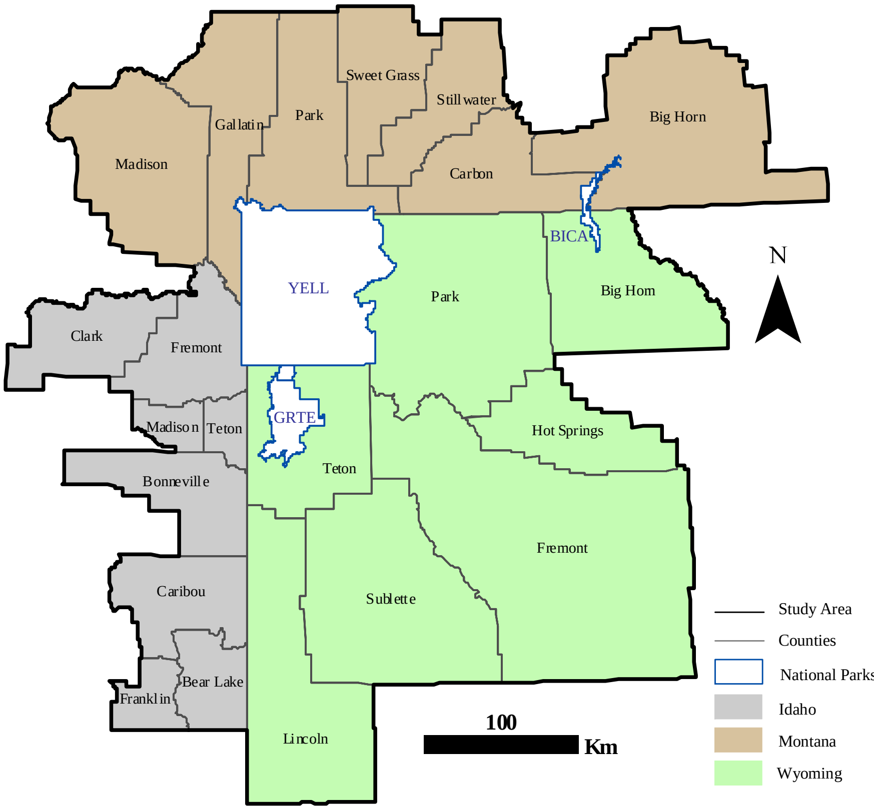
Final Report to the National Park Service
Greater Yellowstone Network

Development of Land Use Change Protocols for The Greater Yellowstone Network



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INTRODUCTION

Nature reserves are often parts of larger ecosystems (Wilcove and May 1986, Newmark 1985). Thus, the protected area within the reserve often does not contain the full range of abiotic conditions, habitats, and processes that are required to maintain native populations and ecological processes within the reserve (Hansen and Rotella 2001). Land use in the unprotected portion of the ecosystem may have negative consequences for reserve ecosystems. Monitoring land use around nature reserves is important for quantifying change and devising management strategies to maintain park functioning. This report presents the rationale and methods for monitoring land use across the Yellowstone area.

The Greater Yellowstone Network (GRYN) of the National Park Service (NPS) Inventory and Monitoring (I&M) Program identified land use change as a top priority vital sign for defining ecosystem health within parks (Jean et al. 2003). The GRYN includes Yellowstone National Park (YELL), Grand Teton National Park (GRTE), and Bighorn Canyon National Recreation Area (BICA), all of which are encompassed within the Greater Yellowstone Ecosystem (GYE), one of the largest ecologically intact ecosystems remaining in North America (Glick and Clark 1998). Lands surrounding the three parks within the GRYN have historically been rural in nature, characterized by low human population densities and natural resource-based, low-intensity land use activities (Rasker and Hansen 2000). Consequently, parks within the GRYN support nearly the full suite of native species present before European settlement.

In recent decades, however, the GYE has been experiencing a substantial shift in predominant land uses. Since 1970, human population size increased an average of 55% within counties of the GYE, and the number of rural homes increased 350% (Hernandez 2004, Hansen et al. 2002). Much of the development occurred at the wildland interface, as demonstrated by a 300% increase in the number of rural homes in areas bordering federal lands (Hernandez 2004). These land use changes within the larger ecosystem could potentially threaten ecological integrity within the three parks of the GRYN.

Understanding linkages between park ecosystem integrity and surrounding land use changes provides a sound scientific basis for identifying monitoring indicators. Hansen and DeFries (in prep) previously described four general mechanisms based on ecological theory which describe potential linkages. Surrounding land use activities may 1) reduce habitat extent, 2) alter or interrupt the flow of energy or materials across the larger ecosystem, 3) eliminate crucial habitats, such as seasonal habitats and migration corridors, and 4) create negative edge effects for periphery park communities. Hansen and Gryskiewicz (2003) incorporated these mechanisms into the development of conceptual models for the Heartland Network's long-term monitoring efforts. The resulting models illustrated linkages between relevant land use change issues and park resources of concern, and ultimately resulted in the identification of land use indicators which were specific to management priorities.

In this current effort for the GRYN, we are using methods similar to those outlined by Hansen and Gryskiewicz (2003) for the Heartland Network. In our Interim Report to the GRYN (Hansen and Jones 2004), we used some of these methods to develop conceptual models and derive monitoring indicators which are relevant to management issues and feasible to measure. These indicators included land cover, housing and road density and distribution, and backcountry recreational use. We then developed draft monitoring objectives which included the most relevant and sensitive indicators.

The objectives of this report are to:

1. Present revised monitoring objectives;
2. Outline a protocol for monitoring indicators of land use change.

The conceptual background for this GRYN effort is outlined by Jones et al. (in review), where they discuss approaches for monitoring land use change in the context of the NPS I&M program.

REVISED MONITORING OBJECTIVES

Monitoring objectives were revised based on discussions with GRYN and park personnel. Recreation was eliminated as a monitoring objective for this vital sign because the development of protocols for monitoring recreational activities is being addressed within the national I&M program. Additionally, other organizations within the network (e.g. Greater Yellowstone Coordinating Committee) have already begun efforts which monitor recreational use. We further revised the objectives by reorganizing them into land cover monitoring, including remotely sensed data products, and land use monitoring, including home and road density and other ancillary data products. Previously, monitoring land use and land cover were included as one objective, while road density was separate. This revision resulted in changes in the organizational structure of the objectives, but did not change the overall content. These are the revised monitoring objectives:

Objective 1 – Quantify change in land cover and some land uses inside and outside parks using remotely sensed data sources

Objective: To quantify the areal extent and landscape pattern of different land cover and use types within parks and in the region surrounding parks through interpretation of remotely sensed data, and to quantify the magnitude of change in the area of each land cover and use type over time. The emphasis will be on urban, agriculture, and natural land cover types.

Justification/Rationale for this objective: Land cover describes the dominant vegetation or ecosystem type. Land use indicates how the place is used by humans. It is important to monitor land cover because change in the extent or pattern of ecosystem types is relevant to park managers and often indicative of land use. Land cover and some land uses (e.g., agriculture) are effectively quantified by classification of remotely sensed data. Remotely sensed data sources are useful because land cover can be mapped over large extents at relatively fine resolutions for repeated time periods. Quantifying change in land cover and use allows for the interpretation of trends in the prevalence of certain land cover and use types over time, which may provide insight into the impacts of current and future land use activities on park natural resources.

Objective 2 – Quantify change in land use inside and outside parks using ancillary data sources

Objective: To quantify rural residential development, urban expansion, road density, and agricultural characteristics using datasets such as county tax assessor information, United States Census Bureau (USCB) data, and other ancillary data sources.

Justification/Rationale for this objective: Many land uses cannot be accurately detected using remote sensing techniques. Non-remotely sensed data, or ancillary data, including county tax assessor records and USCB surveys, can accurately quantify the numbers and densities of homes within rural areas which may not be identified by land cover maps alone. Additionally, as land use within a region becomes more human-dominated, the number and size of roads often increases. Roads can have significant ecological impacts, including the fragmentation of habitats, direct wildlife mortality from collisions with cars, and increased accessibility to backcountry areas resulting in higher levels of human disturbance in remote areas. Therefore, quantifying the extent and characteristics of roads, and monitoring change over time, is relevant for considering the ecological impacts of land use change on ecological condition of parks.

Objective 3 – Analyze land use change in a way that quantifies impacts on the extent and quality of habitats

Objective: To quantify the area and proportion of different indices of biodiversity (e.g. habitat type) that are impacted by certain land use activities, and to quantify how these impacts are changing over time. Additionally, we will identify ecologically important locations undergoing the highest rates of land use intensification. We will emphasize other vital signs identified within the network when analyzing impacts; these vital signs will include cover types and species habitats such as aspen, riparian/riverine, shrub-steppe, whitebark pine, landbirds and other birds of concern, ungulates, and large carnivores

Justification/Rationale for this objective: Measuring land use and change over time will provide an understanding of the characteristics of the surrounding landscape, but will only provide limited inference about the ecological impacts of land use change on park resources. Therefore, we will quantify the area of habitat impacted by particular land use types in order to provide an estimate of the ecological impacts. Additionally, considering the impacts of land use change on other vital signs (i.e. species and habitats of concern) within the network will allow for the integration of monitoring efforts, and provide information about real and potential threats of land use change to these park resources.

MONITORING PROTOCOL

Protocols for monitoring land use change are different from other monitoring protocols within the I&M Program. Instead of data collection through field sampling, established methods for quantifying land use largely focus on the acquisition and manipulation of existing data. Land use data sources include remotely-sensed images which provide information about characteristics of the landscape, or demographic and infrastructure data which provide information about how the land is populated and used. This protocol will include a discussion about potential data sources, instructions for how to acquire, process, and manage the data, and discussion of how to analyze and interpret land use monitoring data so that it is useful for management.

Study Area

Land use will be monitored both inside and outside of the three parks of the GRYN. To delineate the study area boundary, we considered the parks in the context of the surrounding GYE. The boundary of the GYE was first described by Craighead (1991) as the range of the Yellowstone grizzly bear (*Ursus arctos*), and includes the Yellowstone Plateau and surrounding public and private lands extending down to the high plains. Rasker (1991) expanded the boundary to include the twenty counties that fall within the GYE. We drew upon this boundary for delineating the monitoring study area because land use data is often distributed at the county level, and further extended it to include the two counties (Big Horn, Montana and Wyoming) surrounding BICA (Figure 1).

Data Sources

There are no existing long-term programs which monitor land use within the region surrounding parks of the GRYN. Programs such as the United States Geologic Survey (USGS) National Land Cover Dataset (NLCD; Vogelmann et al. 2001) provide the data for monitoring at a national scale, but are often too broad-scale to address specific management objectives of the GRYN. However, there have been many efforts within the GYE which describe methods for either quantifying land cover and use at a given point in time, or investigating historical change. We will incorporate data sources and methods from these national and regional efforts to develop a long term monitoring program for the GRYN.

Remotely Sensed Data Sources

There are many different remotely sensed data sources that have previously been used to classify land cover and use within the study area (Table 1). Here we review potential sources in the context of data availability; spatial, spectral, and temporal resolution; and cost of acquisition. Spatial resolution is a measure of the smallest surface unit that can be resolved by a sensor, spectral resolution refers to the number and type of spectral bands that can be detected, and temporal resolution measures how often a sensor collects data from a certain area (Jensen 1996).

Hyperspectral sensors located on aircraft, such as AVIRIS and Probe-1, allow for the identification of fine-scale features because they gather high resolution data (< 5m) from near-continuous spectral bands. Images from these sensors are useful for classifying small or dispersed land cover patches, such as riparian or aspen (Aspinall 2002). However, processing and analysis of the data over large areas is not feasible due to the large file sizes of high resolution images. Additionally, because of the aircraft platform, data collection is targeted rather than continuous, which limits availability and results in prohibitive costs for large areas.

Conversely, high resolution multispectral sensors housed on satellites, such as IKONOS or QuickBird, provide good availability of data (3-day repeat cycle), and have demonstrated high levels of overall classification accuracy (> 90%; Lawrence et al. 2004). However, methods for classifying land cover using data from these sensors have not yet been tested within the study area, and issues of file size and cost (terrain corrected IKONOS scenes are approximately $38/km^2 plus surcharges) are similar to those for hyperspectral sensors.

MODIS, a moderate resolution (250 – 1000m) multispectral sensor, provides excellent spatial and temporal data availability (global coverage every 1-2 days), has higher spectral resolution (36 bands), and land cover maps are distributed by the government at no cost to the user. However, the relatively coarse spatial resolution of the data (1 km) limits classification to only abundant, more expansive cover types.

The medium resolution, multispectral (7 bands) sensors (TM and ETM+) onboard the Landsat satellites, operated by the National Aeronautical and Space Administration (NASA), provide reasonable temporal availability (16-day repeat cycle) and adequate spatial resolution at a relatively low price. Images can be classified to 30 meter resolution, allowing for the identification of both expansive and more dispersed cover types, while keeping file sizes manageable for processing and analyses. Scenes can be purchased with precision and terrain correction already complete (reducing the time needed for processing) for $625 per scene, with opportunities for bulk discounts. Hence, compared with other sensors, those onboard the Landsat satellites are the best for balancing resolution, cost, and applicability over large extents, and we recommend using this imagery for quantifying land cover in the GRYN.

In the future, as spatial trends emerge from the monitoring data, it may be possible to identify smaller areas which are heavily impacted by land use, or areas with especially patchy habitats, for more detailed classification using hyperspectral images. However, we will not incorporate this into the methodology of the current protocol.

Many land cover and use classification methods using Landsat images have been developed within the GRYN region (Table 1). The challenge is to incorporate methods which will provide information for addressing monitoring objectives, while also considering financial and logistical constraints. We draw upon methods established by Parmenter et al. (2003) and Powell (2004) which describe image classification techniques for dominant land cover classes within the GRYN. This methodology classifies more detailed deciduous and conifer forest cover types, which are not quantified by existing land cover maps such as the NLCD (Vogelmann et al. 2001). Classification of detailed land cover types is necessary because human activities can heavily influence forest age or composition. Consequently, these categories are important indicators of land use change. Although the transformation of raw Landsat images to land cover maps is labor intensive, this methodology is especially relevant and valuable because it has already been validated for a large portion of the study area, and the classification scheme includes cover types relevant to the GRYN.

Ancillary Data Sources

Remote sensors cannot accurately capture the level of detail needed to adequately describe some types of land uses within the GRYN. For example, residential development is often too dispersed and roads too linear to be detected with many sensors. Additionally, different agricultural practices with similar land cover signatures may not be distinguishable in image classification. Consequently, it is necessary to employ supplemental data for monitoring these aspects of land use change. Here we discuss ancillary data sources and classification schemes for monitoring urban and rural residential development, roads, and agriculture within the GRYN study area.

In order to create a complete map of homes, data needs to be acquired which quantifies urban and suburban areas (i.e. cities), and rural residential development. The NLCD includes an urban cover type, but classification accuracy for this category can be low (35% producers accuracy within the study area; United States Environmental Protection Agency 2002). Therefore, it is necessary to incorporate supplemental data. As part of the national decennial census, the USCB collects data that can be used to monitor change in the area of incorporated cities. Boundary files that quantify the extent and distribution of incorporated areas are delineated at the sub-county census block scale and distributed as spatially referenced files. Census blocks within incorporated areas are relatively small (average of 29 hectares in the GRYN study area), so this scale provides an accurate delineation of city boundaries.

The spatial and temporal scales captured by USCB data, however, are not sufficient for characterizing residential development in rural areas. Census blocks in rural areas of the GRYN are very large (up to 150,000 hectares) and variable in size, making it impossible to standardize rural home densities at a fine scale. Also, block boundaries are not permanent and may change over time, which would complicate the identification of long-term trends. Furthermore, it is necessary to monitor rural residential development more frequently than every ten years because significant changes can occur quickly, as previously unoccupied lands become occupied with homes. Gude et al. (in press) demonstrated for the GYE the feasibility and accuracy of using data acquired from county tax offices to quantify rural residential development at finer spatial and temporal scales than does USCB. We will draw on their methods for this protocol. In conjunction with tax assessment, Township/Range/Section (TRS) information is recorded annually for each home located outside of city boundaries. Consequently, home densities can be summarized for every rural section (approximately one square mile / 2.59 square kilometers), allowing for fine-scale monitoring across the entire study area. Tax data is updated on an annual or semi-annual basis, and can be acquired for free or for a nominal fee from either state or county tax offices. The integration of maps quantifying incorporated areas and rural homes will provide complete coverage of residential land use in the study area.

As part of the decennial census, the USCB also distributes TIGER/Line files which include geographic information about roads. This is the most extensive and reliable census of roads within the GRYN study area, and the only source for which roads are updated on a regular basis. TIGER files are used in conjunction with a Geographical Information System (GIS), so that roads can be mapped at 1:100,000 scale across the entire study area. Roads are classified into five categories, including interstates, state and county highways, local roads, and four wheel drive logging roads. These classes are relevant for monitoring because each of these road types represent a different magnitude or type of human use. For example, increase in the numbers of local roads and highways may indicate expansion of residential development, whereas increase in the number of four wheel drive roads may be more indicative of the expansion of recreation or logging. Consequently, change in any class can be an informative indicator of changes in land use overall.

Remote sensors capture the overall distribution of agriculture in the region, but cannot distinguish between specific agricultural uses of the land. Ancillary sources can supplement remote sensing data with information about the extent of various crop types. The United States Department of Agriculture (USDA) National Agriculture Statistics Service (NASS) regularly releases a Census of Agriculture for each county in the US which documents the acres of land used for different types of agriculture. Although these data are collected at a coarse scale (the county level), they are the most comprehensive source of detailed agricultural information that is available for the entire study area. Furthermore, information is reported every five years, so this census is a reliable source of data for long-term monitoring. We will focus on quantifying total land in agriculture, and area of cropland and pastureland for this effort in order to inform about the agricultural land uses that are most relevant to this region.

Methods

Various levels of time, effort, and money are required to transform the remotely sensed and ancillary data into a format for monitoring. Thirty-nine classes (i.e. indicators) of land use and cover are identified and organized into a system comprised of four hierarchical levels, based on the Anderson classification scheme (Anderson et al. 1976). Here we discuss methods for acquiring, processing, and validating the data, as well as provide instruction for generating metadata for each data source. We include in the Appendix a Standard Operating Procedure (SOP) for each data source which details the steps for this process. Table 2 summarizes key attributes of each data source described below.

Land Cover

Data collected onboard the NASA Landsat satellites provide information for monitoring land cover and use change. Sensors capture images quantifying characteristics of the landscape that are indicative of land cover. These images can be used with supplemental data to create land cover maps. Here we summarize methods outlined by Parmenter et al. (2003) and Powell (2004) describing how to create a hierarchical land cover map of the GRYN.

Aerial photographs provide reference data for converting satellite images to land cover, and validation data for assessing classification accuracy. Twenty aerial photo transects spanning gradients of topography and vegetation have been previously identified within the study area (Figure 2). Along each transect, sample plots that are 0.81 ha in size are randomly generated. Aerial photos are then acquired, and vegetation characteristics are interpreted at each sample plot location. Each plot is assigned a Level II cover type (Table 3) based on the dominant vegetation within the plot, i.e. either herbaceous/shrubland, deciduous forest, coniferous forest, water, other natural non-vegetated areas, urban/built-up, or irrigated agriculture. Conifer and deciduous plots are then further interpreted to assign Level III and IV classes (Table 3). For Level III classification, Level II conifer sample plots are further classified to seral stage, including seedling/sapling (~0-40 years old), pole-aged (~40-150 years old), mature (~150+ years old), and mixed seral (no dominant seral stage). For Level IV classification, Level III mature conifer and Level II deciduous are further classified to species, including whitebark pine (*Pinus albicaulis*), Douglas-fir (*Pseudotsuga menziesii*), mixed conifer, aspen (*Populus tremuloides*), willow (*Salix* spp.), and cottonwood (non-aspen *Populus* spp.).

Information collected from aerial photos can then be used with satellite images to create a land cover map of the entire study area. Classification tree analysis (CTA) is used to build a model describing relationships between known vegetation cover types identified in aerial photo plots, and data derived from satellite images at those same locations. Two-thirds of the aerial photo reference data are used to build the model, while the remaining one-third are used to validate the model and assess the accuracy of classification. Data derived from satellite images and used in model-building include spectral reflectance, and tassled-cap derived indices of brightness, wetness, and greeness values. Additionally, elevation, aspect, and slope, which are derived from USGS Digital Elevation Models (DEMs), are incorporated as predictors of cover type to increase the classification accuracy of the CTA model. Level III and IV classes are derived by isolating some Level II cover types for more specific classification. For Level III classification, conifer pixels are further classified to seral stage (Table 3). For Level IV classification, Level III mature conifer and Level II deciduous are further classified to species (Table 3). The classification rules identified by the CTA model are then used to extrapolate cover types across the study area at 30 meter pixel resolution.

Aerial photo and satellite image data can also be used to quantify the density of conifer vegetation, which can be indicative of habitat quality and is relevant to ecosystem functioning. During photo interpretation, sample plots that contain conifer forest are isolated and conifer density quantified by using the point-intercept method. With this method, a ten-dot matrix is overlayed on the photo sample plot, and intersections with conifer forest are recorded, resulting in a description of the fractional composition (in 10% increments) of conifer for each sample plot. These data are then used as reference and validation data for satellite image classification using the same methodology previously described for categorical land cover classification. Level II conifer forest pixels are isolated and regression models are used to identify relationships between air photo reference data of conifer density and characteristics of the satellite images. The regression equation identified by the model is then used to extrapolate conifer cover across the study area at 30 meter pixel resolution.

The resulting land cover map is hierarchical, representing Level II, III, or IV land cover classes. It is necessary to calculate standard measures of accuracy to validate this land cover map. Aerial photo data that was witheld from the model-building set can be used to independently validate classification accuracy. Regression models will further quantify the strength of the relationship between cover types predicted by the model and cover types observed in aerial photos.

We suggest completing an updated land cover map every five years. The entire process of creating the map needs to be repeated for each monitoring period using updated aerial photos and satellite images. Aerial photos of transects located on Forest Service land (Figure 2) can be acquired from the United States Forest Service (USFS) Aerial Photography Field Office in Salt Lake City, Utah or from USFS offices of individual forests. Photos for transects within National Parks (Figure 2) can be acquired from individual park or network aerial photo archives. Additionally, photos of public and private lands may be acquired through the USGS National Aerial Photography Program. Prices for acquisition of aerial photos vary by source. Opportunities may exist to reduce costs through the sharing of photos among interested agencies. Thirteen Landsat images cover the GRYN study area (Figure 2). Classification methodology requires three different seasons (fall, winter, summer) for each image for each monitoring period. Landsat images can be ordered through the internet from the USGS Earth Resources Observation and Science (EROS) Data Center in Sioux Falls, South Dakota. Images can be acquired with precision and terrain correction, reducing the amount of processing needed to be done for monitoring. Each Landsat image costs approximately $625, with an additional 20% discount when more than 25 scenes are ordered.

[Refer to SOP 1 for more detailed instructions.]

Rural Homes and Cities

Data describing rural homes can be collected from county tax assessors offices and state Departments of Revenue. Here we summarize methods described by Hernadez (2004). Rural homes are defined as all homes located on private lands that are outside of incorporated city and town site boundaries, including subdivisions but excluding mobile homes. Homes located on tribal lands are not included in county tax data, so these areas will be excluded from the monitoring database. Tax assessor datasets summarize the number of rural homes per TRS (or 'section'), according to the Public Land Survey System (PLSS).

Data for Montana and Wyoming are distributed as Microsoft Excel spreadsheets through the state Departments of Revenue, and require minimal reorganization to format the databases for monitoring. As of 2002, information for Idaho is collected and managed by the individual county tax assessors. Data from Teton, Caribou, and Bear Lake Counties exist only as hard (non-electronic) copies, and must be compiled and manually entered by the user at the tax offices. The five other Idaho counties will either distribute hard or electronic (Microsoft Excel compatible) copies to the user. Methods for collecting Idaho rural homes data may change as technology is updated for compiling and distributing tax data; this protocol should be updated in the future to reflect this.

To spatially reference the data, databases from the three states can be joined by the unique TRS field to a PLSS basemap in a GIS. The resulting map identifies sections within the study area containing rural homes (Level II; Table 3). Sections can be further classified either agricultural densities of rural homes, with 1-15 homes per section, or exurban densities, with at least 16 homes per section (Level III; Table 3). This exurban threshold in number of homes serves as an important distinction between types of land uses; sections with at least 16 homes are generally more populated than would be expected for working agricultural lands (Brown et al. in press). To assess the accuracy of the tax assessor database, locations of rural homes can be validated using reference data collected from aerial photo interpretation.

Data quantifying the locations of cities is collected and distributed by the USCB in conjunction with the national decennial census. The USCB refers to cities as either ‘incorporated places’ or ‘census designated places’ (equivalent to incorporated places, but not legally defined), and creates GIS polygon files delineating city boundaries that can be downloaded for free by state. The only required processing is to reproject the three state files into the appropriate coordinate system, clip them to include only the study area, and merge them into one file.

We suggest completing an updated rural homes map every five years, and a map of cities every ten years. These two maps should be merged to create one map quantifying residential land uses in the GRYN. For the monitoring periods in which the map of cities is not updated (i.e. every other monitoring period for rural homes), the updated rural homes should be integrated with the most recent map of cities.

[Refer to SOP 2 for more detailed instructions.]

Roads

The USCB also collects data identifying the locations of roads in conjunction with the national decennial census. These data are distributed within TIGER/Line files, which can be downloaded by county and exported in the appropriate projection to GIS line coverages. The 22 county files can be merged to create a single GIS file of the study area. Within the attribute table of the coverage is a field specifying line type (CFCC), with 43 of those categories representing different types of roads. TIGER road classes can be aggregated into a hierarchical classification scheme that includes five Level III classes of roads: interstate, US highway, state/county highway, local road, and four-wheel drive/logging road (Table 3). For monitoring, we suggest completing an updated map of roads every ten years.

[Refer to SOP 3 for more detailed instructions.]

Agriculture

The USDA NASS compiles a county-level Census of Agriculture every five years, and distributes this agricultural information for free on its website. A Microsoft Excel-compatible spreadsheet is available for immediate download after specific data types and counties of interest are identified by the user. The Census of Agriculture data quantifies most of the agriculture monitoring classes, including total agriculture, irrigated and non-irrigated cropland including hay and other crops, and irrigated and non-irrigated pastureland (Table 3). Data for irrigated and non-irrigated cropland and pastureland classes (Levels II – IV) are distributed separately from data for total agriculture (Level I). These two different spreadsheets can be manipulated and merged to create one spreadsheet containing data for each county. This spreadsheet can then be spatially referenced by linking to a county basemap by a unique identifier (i.e. the state/county FIPS number). The final map quantifies all levels of agricultural classes for each of the counties within the GRYN study area. For monitoring, we suggest completing an updated map of agriculture every five years.

[Refer to SOP 4 for more detailed instructions.]

Metadata

'Metadata' is information describing a particular dataset. A metadata text file should be created for each dataset for each monitoring period. Spatial datasets that are acquired from other agencies and used with few modifications (i.e. DEMs for creating land cover maps, USCB incorporated city boundaries, PLSS boundaries for mapping rural homes, county boundaries for mapping detailed agricultural data, and TIGER line files) will usually already have metadata created by the source organization. For all remaining datasets, detailed metadata need to be documented according to Federal Geographic Data Committee (FGDC) standards (FGDC 1998). A template which adheres to these standards is provided within the Environmental Systems Research Institute (ESRI) ArcGIS software program (ESRI 2002), and can be used to create metadata for land use monitoring datasets.

<u>Analyses of Monitoring Data</u>

Analyses of monitoring data will include routine data summaries to quantify land use and cover metrics, and assessment of change in those metrics over time. Suggested time intervals for data summaries and change assessment are the same as for data collection (see 'Time Scale for Monitoring', Table 2). We will also discuss integrating the four land use maps (land cover, residential land use, roads, and agriculture) with each other and with other ecological response data to add-value to monitoring data and increase interpretability and relevance for management.

Quantify Metrics

There are many possible ways to measure characteristics of land use. We will focus on those that quantify extent and landscape pattern of land cover and use classes. Extent and pattern are good indicators for monitoring the condition and use of the landscape, and meaningful for interpreting change over time (Heinz Center 2002).

Metrics for each Level II, III, and IV land cover class (i.e. those derived from Landsat data; Table 3) include total area (km^2), relative abundance (%), number of patches and average patch size (m^2), and mean distance (m) to the nearest patch of the same class type, i.e. 'nearest neighbor' (Table 4). For the Urban/Built-up class, only total area and relative abundance are relevant. The free software program FRAGSTATS (McGarigal et al. 2002), which is able to compute landscape metrics for grid-based land cover maps, can be used to conduct these analyses. Conifer density can be quantified as the total area and relative abundance of conifer forest falling within each 10% increment of cover

Metrics for Level III and IV Urban/Built-up land uses will quantify the number and extent of each land use class (Table 4). For the Level III class of rural homes, the total number of homes will be recorded for each square mile section. Sections containing rural homes will then be further classified (Level IV) as supporting either agricultural (1-15 homes) or exurban (16 or greater homes) densities of homes. The total area impacted by homes and relative abundance of impacted land will then be calculated. The area of land (km^2) impacted by agricultural densities of homes equates to the actual area included in those sections. The area of land impacted by exurban densities of homes equates to the actual area included in those sections, plus a one mile (2.59 km) buffer surrounding each section. The Level III incorporated cities class (Table 4) will be measured as the area of land encompassed within city boundaries, plus a one mile (2.59 km) buffer. Exurban and cities are buffered to reflect the far-reaching ecological effects that higher-density residential areas can have on surrounding unoccupied lands (Hansen et al. in press). Relative abundance will also be calculated for all of these classes to quantify the percentage of the area of the landscape influenced by residential land uses. To quantify characteristics of roads, total length will be calculated for each of the five Level IV classes (Table 4).

Level I, III, and IV agricultural classes derived from USDA NASS Census of Agriculture data (Table 3) will be measured by the area (acres) of each class and the proportion of land encompassed by each class. Metrics will be summarized for each county within the GRYN study area (Table 4).

Metrics can also be calculated from integrated land use and cover maps. These metrics will quantify the area and spatial pattern of natural land cover after considering the influences of land use. We suggest overlaying residential land use and land cover maps in a GIS to calculate the total area (km^2) of each cover type influenced by cities and exurban densities of rural homes, and the percent of the total area of that cover type that is impacted. Additionally, the spatial pattern of unimpacted lands can be quantified by "erasing" cities and sections with exurban densities of rural homes from the land cover map. The number of patches and average patch size (m^2), and the mean distance to nearest neighbor (m) can then be calculated for land cover not influenced by residential land use. This analysis can be conducted for all natural land cover types. Alternatively, analysis can focus only on the natural land cover types that are of high management priority for parks (e.g. whitebark pine, aspen, cottonwood, etc.).

Assess Change

An integral part of monitoring is assessing how resources are changing over time. Changes in characteristics of land use and cover are usually expressed as rates of change from one time period to the next. Change in all of the metrics described above for land cover, rural and urban residential, roads, agriculture, and integrated land use and cover (Table 4) will be assessed in this way. Specifically, percent change will be calculated as [(current value – value at last time period)/value at last time period]. For example, if there are 50 rural homes in a given section in one time period, and 75 homes in the next time period, the rate of change would be [(75-50)/50] = 0.5, or 50%. Rates of change in characteristics of land cover and use can be charted starting with the second monitoring time period, and trend analysis should occur at each monitoring time period after that.

Additionally, trajectories of change can be calculated by overlaying maps from two time periods. Trajectories quantify change in cover type or seral stage at a given location. Knowledge of trajectories can provide information about mechanisms and pathways of observed percent changes in cover types over time. Parmenter et al. (2003) conducted trajectory analyses for the GYE to quantify changes in vegetation from 1975 to 1995 (Figure 3). Trajectories of change in the GRYN can be calculated for land cover classes by overlaying the most recent land cover map with the map from the previous time period.

Knowledge of past and current rates of change can also allow for the projection of future changes in land use. Monitoring data can be used to parameterize models that predict land use change. Potential applications include projections of buildout or alternative growth scenarios using rural homes data, or projections of future road expansion around park borders. For example, Gude et al. (in prep) projected potential alternative growth scenarios for rural home development in the GYE based on observed historical rates of growth (Figure 4). Using monitoring data to simulate future land use scenarios allows for the evaluation of potential impacts of land use on park resources and can help to inform management decisions.

Integrate Monitoring Data with Other Data Sources

Land use maps can be integrated with maps showing locations of natural resources inside and outside of parks to better understand impacts of land use. These natural resource data are not collected within the land use monitoring program, but can potentially be acquired from other monitoring efforts occurring within the GRYN or the larger region. Potential data sources include animal species distribution and habitat use (e.g. grizzly bear, elk, birds, fish, amphibians, etc.), vegetation communities not captured through remote sensing (e.g. exotic plant species, wetlands), or areas of particular biological or conservation value (e.g. biodiversity hotspots, migration corridors). Maps representing natural resources can be overlayed with land use maps to calculate metrics quantifying the area of habitat impacted by land use, and the distribution and pattern of habitat across the landscape. Specific steps for analyses will depend upon future assessments of available data sources and the identification of natural resources of management concern. Long-term cooperation with other researchers within the GRYN monitoring program and the larger region may allow for the examination of trends describing the relationships between land use and high-priority natural resources over time. Gude et al. (in prep) provide a good example of how the integration of rural homes data and natural resource data can quantify the potential impacts of land use on ecosystems and communities within the GYE (Figure 5). These types of analyses within the GRYN can provide valuable information for future park management decisions.

REPORT FORMATS AND DATA ARCHIVES

We recommend that a land use monitoring report be completed every five years. Each report will include new data and analyses for land cover, rural homes, and agriculture. Every other report (i.e. every ten years) will include new data and analyses for cities and roads. For reports where new data for cities and roads are not available, results from the most current data and analyses should be reported. Copies of databases for quantifying each class of land use and cover for the current monitoring period should accompany every report. Each 5-year report should include:

Land Cover

- Map representing the 6 Level II classes of land cover (Table 3). See Figure 6 as an example.
- Map representing the 10 Level III and IV land cover classes (Table 3), plus Level II Herbaceous/Shrubland, Water, Other natural non-vegetated, and Urban/Built-up.
- Table presenting the results of the accuracy assessment from the current land cover classification. See Figure 1-1 in the Appendix as an example.

- Table displaying results for all of the metrics calculated for each land cover class for the current monitoring period, as well as metrics from all previous monitoring periods, and percent change since monitoring began. See Table 5 as an example.
- Table showing results for all of the metrics calculated for each land cover class after considering the influences of residential land uses (i.e. cities and exurban). Include metrics for the current monitoring period, as well as metrics from all previous monitoring periods, and percent change since monitoring began. See Table 5 as an example.
- Narrative about current characteristics of land cover based on results of analyses, and discussion about trends in land cover change over time.
- GIS raster grid of land cover for the current monitoring period. Grids from previous monitoring periods should be archived.

Rural Homes and Cities

- Integrated map representing residential land use classes, including no homes, agricultural or exurban densities of rural homes, and incorporated cities. See Figure 7 as an example.
- Table displaying results for all of the metrics calculated for each residential land use class for the current monitoring period, as well as metrics from all previous monitoring periods, and percent change since monitoring began. See Table 6 as an example. Results for analyses of cities will change only every other report (i.e. every 10 years). For reports in which analyses for cities does not change, report the results from the most current data on cities.
- Results of the accuracy assessment for rural homes, including the mean difference and standard deviation between the counts of rural homes per section in the aerial photo data and the tax data. This should also include the p-value from the paired t-test analysis.
- Narrative about current characteristics of residential land use based on results of analyses, and discussion about trends in residential land use change over time.
- Updated GIS polygon coverage or shapefile of rural homes and cities. Data from the current monitoring period should be appended to the GIS file from the previous monitoring period, so that there is only one file of residential land uses that is updated every monitoring period.

Roads

- Map representing the 5 Level IV road classes (Table 3).
- Table showing the total length calculated for each Level III and IV class of roads for the current monitoring period, as well as metrics from all previous monitoring periods, and percent change since monitoring began. See Table 7 as an example. Results for analyses of roads will change only every other report (i.e. every 10 years). For reports in which analyses for roads does not change, report the results from the most current data on roads.
- Narrative about current characteristics of roads based on results of analyses, and discussion about trends in changes in the extent of roads over time.
- GIS line coverage or shapefile of roads for the current monitoring period. Line coverages or shapefiles from previous monitoring periods should be archived.

Agriculture

- Map representing the relative abundance of agricultural land use (i.e. Level I Agriculture class).
- Table presenting the results for all of the metrics calculated for each of the agricultural land use class (Table 3) for the current monitoring period, as well as metrics from all previous monitoring periods, and percent change since monitoring began. See Table 8 as an example.
- Narrative about current characteristics of agricultural land uses based on results of analyses, and discussion about trends in agricultural land use change over time.
- Updated GIS polygon coverage or shapefile of agriculture. Data from the current monitoring period should be appended to the GIS file from the previous monitoring period, so that there is only one file of agricultural land use that is updated every monitoring period.

UPDATING THE PROTOCOL IN THE FUTURE

In this protocol we have described methods for monitoring land use change based on currently available information. In the future, as technological advances emerge, it will be necessary to periodically evaluate new data sources and methodologies for monitoring. For example, satellites may be launched that provide new images for assessing land cover; programs may emerge that provide detailed agricultural data at a finer spatial scale; or regional sources of data on roads and urban areas may become available at shorter time intervals. Additionally, changes may occur in how organizations collect and distribute data used in this protocol. In the future, methods should be updated to reflect these types of changes.

However, it is crucial that the data collected for monitoring are comparable and consistent over time so that trends may be quantified. When considering new data sources or methods for this protocol, it is important to evaluate: the spatial and temporal scale of data, the ability to infer from the data specific answers to monitoring questions, how and when the data is collected, and the basic limitations and assumptions of the data. If potential data sources are not comparable with past data, it is better to continue using sources and methods currently established in the protocol.

We suggest assigning each version of the protocol with a number, such as the year it was modified, in order to document changes in the protocol over time. Each monitoring dataset should also be tagged with the protocol version number to allow for identification of the methods and data sources used to create that dataset.

LITERATURE CITED

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. Geological Survey Professional Paper 964, United States Department of Interior, Geological Survey. US GPO, Washington, DC. 36 pp.

Aspinall, R. and D. Pearson. 2000. Integrated geographical assessment of environmental condition in water catchments: Linking landscape ecology, environmental modelling, and GIS. Journal of Environmental Management 59: 299-319.

Aspinall, R.J. 2002. Use of logistic regression for validation of maps of the spatial distribution of vegetation species derived from high spatial resolution hyperspectral remotely sensed data. Ecological Modelling 157: 301-312.

Brown, D.G., K.M. Johnson, T.R. Loveland, and D.M. Theobold. In press. Rural land use trends in the conterminous U.S., 1950-2000. Ecological Applications.

Burrough, P.A., J.P. Wilson, P.F.M. van Gaans, and A.J. Hansen. 2001. Fuzzy-k means classification of topo-climatic data as an aid to forest mapping in the Greater Yellowstone Area, USA. Landscape Ecology 16:523-546.

Craighead, J.J. 1991. Yellowstone in transition. Pp. 27-40 *in*: Kieter, R.B. and M.S. Boyce (Editors). The Greater Yellowstone Ecosystem: Redefining America's Wilderness Heritage. Yale University Press, New Haven, CT.

Debinski, D.M., K. Kindscher, and M.E. Jakubauskas. 1999. A remote sensing and GIS-based model of habitats and biodiversity in the Greater Yellowstone Ecosystem. International Journal of Remote Sensing 20: 3281-3291.

Environmental Systems Research Institute (ESRI). 1999. Arcview GIS release 3.2 for Windows. Redlands, CA.

Environmental Systems Research Institute (ESRI). 2002. ArcGIS release 8.3 for Windows. Redlands, CA.

Federal Geographic Data Committee (FGDC). 1998. Content Standard for Digital Geospatial Metadata. FGDC-STD-001-1998. Washington, DC. 90 pp.

Glick, D.A. and T.W. Clark. 1998. Overcoming boundaries: The Greater Yellowstone Ecosystem. Pp. 237-256 *in* Knight, R.L. and P.B. Landres (Editors). Stewardship Across Boundaries. Island Press. Washington, DC.

Gude P.H., A.J. Hansen, R. Rasker, and B. Maxwell. In press. Rates and drivers of rural residential development in the Greater Yellowstone. Landscape and Urban Planning.

Gude, P.H., A.J. Hansen, and D.A. Jones. In prep. Biodiversity consequences of alternative future land use scenarios in the Greater Yellowstone.

Hansen, A.J., J.J. Rotella, M.P.V. Kraska, and D. Brown. 1999. Dynamic habitat and population analysis: An approach to resolve the biodiversity managers dilemma. Ecological Applications 9: 1459-1476.

Hansen, A.J. and J.J. Rotella. 2001. Nature reserves and land use: Implications of the "Place" principle. Pp. 57-75 *in* Dale, V. and R. Haeuber (Editors). Applying Ecological Principles to Land Management. Springer Verlag, New York, NY.

Hansen, A.J., R. Rasker, B. Maxwell, J.J. Rotella, J.D. Johnson, A. Wright Parmenter, U. Langner, W.B. Cohen, R.L. Lawrence, and M.P.V. Kraska. 2002. Ecological causes and consequences of demographic change in the New West. BioScience 52: 151-162.

Hansen, A.J. and D.A. Gryskiewicz. 2003. Interactions between Heartland National Parks and Surrounding Land Use Change: Development of Conceptual Models and Indicators for Monitoring. Final Report to the National Park Service Heartland Network. August 30, 2003. 73 pp.

Hansen, A.J. and D.A. Jones. 2004. Development of Land Use Change Protocols for the Greater Yellowstone Network: Interim Report to the National Park Service Greater Yellowstone Network. May 27, 2004. 41 pp.

Hansen, A.J., R.L. Knight, J. Marzluff, S. Powell, K. Brown, P. Hernandez, and K. Jones. In press. Effects of exurban development on biodiversity: Patterns, mechanisms, research needs. Ecological Applications.

Hansen, A.J. and R. Defries. In prep. Ecological mechanisms linking nature reserves to surrounding lands: A conceptual framework for assessing implications of land use change.

Heinz Center. 2002. The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States. Cambridge University Press, New York, NY. 288 pp.

Hernandez, P.C. 2004. Rural Residential Development in the Greater Yellowstone: Rates, Drivers, and Alternative Future Scenarios. MS Thesis, Montana State University, Bozeman, MT. 177 pp.

Jakubauskas, M.E. 1996. Thematic Mapper characterization of lodgepole pine seral stages in Yellowstone National Park, USA. Remote Sensing of Environment 56: 118-132.

Jakubauskas, M.E. and K.P. Price. 1997. Empirical relationsips between structural and spectral factors of Yellowstone lodgepole pine forest. Photogrammetric Engineering and Remote Sensing 63: 1375-1381.

Jean, C., S.D. Bischke, and A.M. Schrag. 2003. Greater Yellowstone Inventory and Monitoring Network Vital Signs Monitoring Plan: Phase II Report. September 30, 2003. National Park Service, Greater Yellowstone Network, Bozeman, MT. 99 pp. plus appendices.

Jensen, J.R. 1996. Introductory Digital Image Processing: A Remote Sensing Perspective. Prentice Hall, Inc., Upper Saddle River, NJ. 316 pp.

Jones, D.A., K. Bly-Honness, J.I. Paugh, A.J. Hansen, K. Doherty, J.P. Verschuyl, R. Carle, and S.J. Story. In review. A framework for monitoring land use in and around national parks.

Kokaly, R.F., D.G. Despain, R.N. Clark, and K.E. Livo. 2003. Mapping vegetation in Yellowstone National Park using spectral feature analysis of AVIRIS data. Remote Sensing of Environment 84: 437-456.

Lawrence, R., A. Bunn, S. Powell, and M. Zambon. 2004. Classification of remotely sensed imagery using stochastic gradient boosting as a refinement of classification tree analysis. Remote Sensing of Environment 90: 331-336.

Leica Geosystems. 2003. ERDAS Imagine software, version 8.7. Leica Geosystems, GIS and Mapping Division, Heerbrugg, Switzerland.

MathSoft, Inc. 2000. S-PLUS 6 Guide to Statistics Vol. 2. Data Analysis Division, MathSoft, Inc., Seattle, WA. 618 pp.

McGarigal, K., S.A. Cushman, M.C. Neel, and E.Ene. 2002. FRAGSTATS: Spatial pattern analysis program for categorical maps. Version 3.3. University of Massachussets, Amherst, MA. URL http://www.umass.edu/landeco/research/fragstats/fragstats.html.

Merrill, E.H., M.K. Bramble-Brodahl, R.W. Marrs, and M.S. Boyce. 1993. Estimation of green herbaceous phytomass from Landsat MSS data in Yellowstone National Park. Journal of Range Management 46: 151-157.

Microsoft Corporation. 2002. Microsoft Office 2002. Microsoft Coporation, Seattle, WA.

Newmark, W.D. 1985. Legal and biotic boundaries of western North American National Parks: A problem of congruence. Biological Conservation 33: 197-208.

Parmenter, A., A. Hansen, R. Kennedy, W. Cohen, U. Langner, R. Lawrence, B. Maxwell, A. Gallant, and R. Aspinall. 2003. Land use and land cover change in the Greater Yellowstone Ecosystem: 1975-95. Ecological Applications 13: 687-703.

Powell, S. L. 2004. Conifer Cover Increase in the Greater Yellowstone Ecosystem: Rates, Extent, and Consequences for Carbon. PhD Dissertation, Montana State University, Bozeman, MT. 149 pp.

Price, K.P. and M.E. Jakubauskas. 1998. Spectral retrogression and insect damage in lodgepole pine successional forests. International Journal of Remote Sensing 19: 1627-1632.

R Development Core Team. 2003. R: A language and environment for statistical computing. Version 1.7.1. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org.

Rasker, R. 1991. Rural development, conservation, and public policy in the Greater Yellowstone Ecosystem. Society and Natural Resources 6: 109-126.

Rasker, R. and A.J. Hansen. 2000. Natural amenities and population growth in the Greater Yellowstone region. Human Ecology Review 7: 30-40.

SAS Institute. 2001. SAS/STAT user's guide, Version 8. SAS Institute, Inc., Cary, NC.

Turner, M.G., W.W. Hargrove, R.H. Gardner, and W.H. Romme. 1994. Effects of fire on landscape heterogeneity in Yellowstone National Park, Wyoming. Journal of Vegetation Science 5: 731-742.

United States Environmental Protection Agency. 2002. 1992 NLCD Accuracy Website. URL http://www.epa.gov/mrlc/accuracy.html.

Vogelmann, J.E., S.M. Howard, C.R. Larson, B.K. Wylie, and N. Van Driel. 2001. Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammatic Engineering and Remote Sensing 67: 650–662.

Wessels, K.J, R.S. DeFries, J. Dempewolf, L.O. Anderson, A.J. Hansen, S.L. Powell, and E.F. Moran. 2004. Mapping regional land cover with MODIS data for biological conservation: Examples from the Greater Yellowstone Ecosystem, USA and Para State, Brazil. Remote Sensing of Environment 92: 67-83.

Wilcove, D.S. and R.M. May. 1986. National park boundaries and ecological realities. Nature 324: 206-207.

APPENDIX: STANDARD OPERATING PROCEDURES

SOP 1. Monitoring and Analyses of Land Cover Change

1. Develop reference and validation data from aerial photos.
    a. Acquire aerial photos for the twenty transects; '***transects.shp***' shows the locations of the transects.
        i. Most transects are located on USFS land. First contact individual Forest Service offices, including Bridger-Teton, Gallatin, Custer, Beaverhead-Deerlodge, Caribou-Targhee, and Shoshone National Forests, to investigate potential data sharing of existing aerial photos. Photos of Forest Service lands can also be acquired from the USDA Aerial Photography Field Office in Salt Lake City, Utah.
        ii. Photos for transects located within National Parks may often be acquired from the photo archives of the specific park.
        iii. For all other transects, the USGS National Aerial Photography Program may be able to provide photos of public and private lands.
    b. Using random sampling within the transects, generate as many 0.81 ha plots as possible. Interpret those sample plots that do not share an edge with another plot, are not located in a distorted region of the photo, and do not contain more than two of the three Level II natural vegetation types (i.e. conifer forest, deciduous forest, herbaceous/shrubland; Table 1-1). For example, Powell (2004) interpreted 2,144 sample plots within the twenty transects.
    c. Interpret sample plots categorically based on the hierarchical classification scheme (Table 1-1).
        i. Level II = Assign all plots either herbaceous/shrubland, deciduous forest, coniferous forest, irrigated agriculture, water, other natural non-vegetated, or urban/built-up.
        ii. Level III = Further interpret Level II conifer plots to seral stage (Table 1-1), including seedling/sapling (~0-40 years old), pole-aged (~40-150 years old), mature (~150+ years old), and mixed seral (no dominant seral stage).
        iii. Level IV = Further interpret Level III mature conifer and Level II deciduous forest to species (Table 1-1), including whitebark pine, Douglas-fir, mixed conifer, aspen, willow, and cottonwood.
    d. Interpret sample plots for conifer density to quantify the fractional composition of conifer forest within each plot.
        i. Isolate sample plots containing Level II conifer forest.
        ii. Using the point-intercept method (Parmenter et al. 2003), place a 10-dot matrix over each plot. Record the cover type intersecting each dot to quantify the fractional vegetation components (in 10% increments) of each plot.
2. Process the Landsat satellite imagery.
    a. Obtain three different seasonal images (e.g. summer, winter, fall) for each of the thirteen Landsat scenes; '***landsat.shp***' shows the locations of the scenes. (Although three seasons is optimal, it is also acceptable to use only two seasonal images for each scene if necessary.) Path/Row numbers for the thirteen images include: 36/28, 36/29, 36/30, 39/28, 39/29, 37/28, 37/29, 37/30, 37/31, 38/28, 38/29, 38/30, and 38/31. Order these scenes from the USGS EROS Data Center

website http://edc.usgs.gov . Choose the option which includes precision and terrain correction; these images have been corrected radiometrically, geometrically, and for precision, and DEMs have been incorporated to correct errors due to topographic relief.

   b. Conduct image-to-image geometric, radiometric, and atmospheric (including haze) correction for each set of seasonal images (e.g. all thirteen summer images). This ensures compatibility in spectral reflectance values across images.
   c. Mosaic the thirteen scenes to create one image for each season.
   d. For each image, compute values of tasseled-cap brightness, wetness, and greeness from sensor reflectance values.
   e. Mask out unwanted pixels, including clouds, cloud shadows, and bad scan lines.

3. Conduct categorical vegetation classification.
   a. Use classification tree analysis ["tree" function in the S-PLUS language (MathSoft, Inc. 2000)] to derive Level II, III, and IV classes from the satellite images.
   b. Build a classification tree model with cover type as the response variable. Include as predictor variables: reflective Landsat spectral bands 1-5 and 7 from each season; tasseled-cap brightness, greeness, and wetness indices; images depicting differences in tasseled-cap brightness, greeness, and wetness across seasons; and elevation, slope, and aspect from the DEM.
   c. Randomly select two-thirds of the aerial photo data as reference data for building the model, and hold out the remaining one-third of the data for validating the accuracy of the classification.
   d. The classification tree model quantifies the relationship between the cover types identified in aerial photo interpretation and the values of the predictor variables at each of the sample plot locations.
   e. Map out the regression equation identified in the classification tree model across the entire study area at 30 meter resolution (i.e. the resolution of the satellite images). Create Level III and IV cover types by subsetting the appropriate Level II and III pixels for further classification (Table 1-1).
4. Conduct classification of conifer cover density.
   a. Mask out all Level II pixels except conifer forest and herbaceous/shrubland.
   b. To maximize the correlation between spectral reflectance and the conifer cover aerial photo reference data, integrate all spectral reflectance data from the satellite images into one index using canonical correlation analysis. Spectral reflectance data include Landsat bands 1-5 and 7 for each season, and the tasseled-cap brightness, greeness, and wetness indices.
   c. Develop a RMA regression model to identify a linear relationship between the spectral reflectance index and density of conifer cover in aerial photo plots.
   d. Use the regression identified in the model to map conifer cover density across the study area. Resample the continuous conifer cover to 10% increments.
5. Compare model predictions to observed cover types in the validation set of aerial photo data. Calculate standard measures of accuracy, including overall, producer's, and user's accuracies. Figure 1-1 reports Powell's (2004) accuracy assessment for Levels II, III, and IV classes.

   a. Overall accuracy is the percent of all pixels that were correctly classifed [number of correctly classified / total].
   b. Producer's accuracy is the probability that a reference sample (i.e. cover type from photo interpretation) will be correctly classified on a satellite image, and measures errors of omission [i.e. those correctly classified for each class / column total].
   c. User's accuracy is the probability that a pixel on a satellite image is classified correctly compared with reference data, and measures errors of commission [i.e. those correctly classified for each class / row total].
6. Additionally, use regression models to further quantify the strength of the relationship between predicted and observed cover (i.e. r^2, root MSE, model variance ratio).
7. We recommend creating a new map every 5 years by repeating the above steps with updated Landsat imagery and aerial photos.
8. Calculate metrics for each land cover class (Table 1-1) every 5 years, including:
   a. Total area (km^2) and relative abundance (%).
   b. Number of patches and average patch size (m^2).
   c. Average distance to nearest neighbor (m).
9. Every 5 years, evaluate percent change for each of these metrics, i.e. [(current value – value at last time period)/value at last time period].
10. Calculate metrics for trajectories of change in land cover classes.
   a. Add the most recent land cover map and the land cover map from the previous monitoring period into a GIS.
   b. Conduct overlay analyses to calculate change in cover type for each pixel over time.
   c. Summarize net gains and losses of percent cover change for each land cover class (see Figure 3 as an example).

Table 1-1. Monitoring classes derived from Landsat satellite images.

Level I	Level II	Level III	Level IV
Natural vegetated			
	Herbaceous / Shrubland		
	Deciduous forest		
			Aspen
			Willow
			Cottonwood
	% Conifer forest		
		Seedling/ Sapling	
		Pole-aged	
		Mature	
			Whitebark pine
			Douglas-fir
			Mixed conifer species
		Mixed seral	
Natural non-vegetated			
	Water		
	Other		
Agriculture			
	Irrigated agriculture		
Non-natural non-vegetated			
	Urban / Built-up		

Figure 1-1. Powell (2004) assessments of classification accuracy for a) Level II classes, b) Level III classes, and c) Level IV classes. Level III woodland is the same as ‘mixed seral’ in the monitoring classification scheme (see Table 1-1).

a)

Classified Data	Reference Data			Row total	Producer's accuracy (%)	User's accuracy (%)
	Conifer	Deciduous	Grass-Shrub			
Conifer	397	11	14	422	90	94
Deciduous	7	31	1	39	69	79
Grass-Shrub	36	3	77	116	84	66
Column total	440	45	92	577		
Overall accuracy = 505/577 = 88%						

b)

Classified Data	Reference Data				Row total	Producer's accuracy (%)	User's accuracy (%)
	MOG	Pole	Seed/sap	Woodland			
MOG	80	23	10	8	121	86	66
Pole	9	28	0	1	38	52	74
Seed/sap	0	1	30	2	33	67	91
Woodland	4	2	5	38	49	78	78
Column total	93	54	45	49	241		
Overall accuracy = 176/241 = 73%							

Note: abbreviations are as follows: MOG = mature/old-growth conifer; Pole = pole seral conifer; Seed/sap = seedling/sapling seral conifer; Woodland = conifer woodland

c)

Classified Data	Reference Data			Row total	Producer's accuracy (%)	User's accuracy (%)
	Doug-fir	Mixed con	Whitebark			
Doug-fir	44	23	0	67	69	66
Mixed con	18	90	24	132	73	68
Whitebark	2	10	26	38	52	68
Column total	64	123	50	237		
Overall accuracy = 160/237 = 68%						

SOP 2. Montioring and Analyses of Change in Residential Land Use

I. Create a map of rural homes.
   1. Contact tax offices for each county in Montana to get permission to acquire homes data from state Departments of Revenue. Contact Wyoming Department of Revenue to acquire homes data for Wyoming (Table 2-1). Data are distributed as Microsoft Excel compatible spreadsheets.
   2. Spreadsheets contain one record for each house, with associated TRS. Montana data are distributed as one file with information for all counties. For Wyoming, there is one database file for each county. For each database file, make sure that the fields are listed in the same order, then merge all Wyoming counties into one database.
   3. Reorganize the Montana and Wyoming spreadsheets so that there is one record for every TRS and a field which provides a count of the number of homes in that section.
      a. Concatenate TRS information into one field.
      b. Aggregate records based on the TRS field. Since each record represents one home, when aggregating take the count of the number of records for each unique TRS, naming this field 'homes_xx', with xx indicating the year the data was collected. Save as a .dbf.
   4. Contact each Idaho county tax office to acquire data for that state (Table 2-1). Some counties may require that you visit the office and enter the data into your own laptop computer to create a homes database (e.g. Teton, Caribou, and Bear Lake counties in 2001). Other counties may send the data as hard copies that you need to enter into a computer at your own office. Still others may send Microsoft Excel compatible spreadsheets. Organize these databases in the same manner as was done for Montana and Wyoming, with one record identifying each unique TRS, and an associated count of homes for that time period. Methods for collecting Idaho rural homes data may change as technology is updated for compiling and distributing tax data. Additionally, contact information for acquiring data sources may change. The SOP should be updated in the future to reflect these changes.
   5. Merge the three state databases into one .dbf file.
   6. For the initial monitoring period:
      a. Download the PLSS basemap (which depicts section boundaries) from the National Atlas website http://nationalatlas.gov. Reproject the shapefile to the correct projection UTM zone 12, units meters, datum NAD83. In a GIS (e.g. ArcView), clip the PLSS file to the study area using ***'studyarea.shp'***.
      b. Add the rural homes database to the GIS (e.g. ArcView).
      c. Make sure the format of the data in the TRS field is the same in the PLSS attribute table and the homes database. Join these tables by the unique TRS field to create a table containing a unique TRS and number of rural homes for each record in the table. Save this joined file as a new shapefile (e.g. ruralhomes.shp).
   7. For subsequent monitoring periods:
      a. Add the .dbf from the current monitoring period and the shapefile from the previous monitoring period (e.g. ruralhomes.shp) to a GIS.
      b. Make sure the format of the data in the current rural homes database is the same as the format in the shapefile. Join the tables of the database and the shapefile by the unique TRS field. Save this join as a shapefile with this appended attribute

table so that it includes the new field from the current monitoring period and the fields from previous monitoring. This new shapefile should then replace the one from the previous monitoring period.

8. Some of the sections in the PLSS are much larger than one square mile, so a standardized field of home density needs to be created for each section. Create a new field representing the area of each TRS (i.e. each record) in square mile units (this will already have been done after the initial monitoring period), then create another new field representing the density of homes per square mile (i.e. number of homes / square miles).
9. Conduct an accuracy assessment of the rural homes data for the current monitoring period.
    a. Randomly choose 75 PLSS sections as a sample for validation
    b. Acquire aerial photos (1:16,000 scale or greater) and interpret the locations of rural homes in those sections.
    c. For each section, compare the number of rural homes in the tax database to the number of homes in the aerial photo database.
    d. Use paired t-tests to test the null hypothesis that the mean of the differences in counts of homes per section between the tax data and the aerial photo data is zero.
10. We recommend completing a new map every 5 years using updated rural homes data.

II. Create a map of incorporated cities.
1. Go to USCB website www.census.gov . Navigate to the 'Geography' page and the 'Boundary Files'.
2. Download by state the files of 'Incorporated Places/Census Designated Places'. File format can either be a compressed GIS polygon coverage, or a shapefile.
3. Reproject the files into UTM zone 12, units meters, datum NAD83.
4. Open the files in a GIS (e.g. ArcView) and clip each state to the study area using the file '***studyarea.shp***'. Merge the three clipped files into one.

III. Integrate rural homes with cities to make one map of residential land use.
1. Add the rural homes map and the cities map into a GIS (e.g. ArcView).
2. Add a field to the attribute table of the city boundaries map called 'homes_xx', where 'xx' indicates the year the data was collected. This field will correspond with one in the rural homes attribute table.
3. Enter '-999' as the value for all records in the 'homes_xx' field.
4. 'Erase' the rural homes shapefile using the city boundaries map to eliminate any areas of overlap between the two maps.
5. Merge the city boundaries shapefile into the rural homes shapefile to create one shapefile depicting all residential land uses in the GRYN. The 'homes_xx' field will contain the actual number of homes for rural sections, and '-999' for non-rural (i.e. cities) areas.
6. The cities map is updated less frequently (every 10 years) than the rural homes map (every 5 years). For the monitoring period where the cities map is not updated, integrate the rural homes map with the most recent cities map (i.e. the map from the previous monitoring period).

IV. Calculate metrics for each residential land use class.
1. Calculate metrics for the rural homes classes every 5 years, including:
    a. Level III Homes = Total # of homes
    b. Level IV Agricultural and exurban densities of homes = Area of land impacted (km^2), relative abundance of impacted land compared to total land area (%).

    i. Area of land impacted for sections with agricultural densities of homes equates to the area contained within each section.
    ii. Area of land impacted for sections with exurban densities of homes equates to the area contained within each section, plus a mile (2.59 km) buffer around each section.

2. Every 5 years, evaluate percent change since previous monitoring periods for each of these rural homes metrics, i.e. [(current value – value at last time period)/value at last time period].
3. Calculate metrics for the 'incorporated cities' class every 10 years, including:
    a. Total area (km^2) impacted by cities, and relative abundance compared to total land area (%).
    b. Area of cities equates to the actual area within the city boundary, plus a one mile (2.59 km) buffer around each city.
4. Every10 years, evaluate percent change since previous monitoring periods for each of these metrics, i.e. [(current value – value at last time period)/value at last time period].

V. Every 5 years, calculate integrated metrics using the residential land use and land cover maps.
    1. Add the land cover map and the residential map to a GIS.
    2. Conduct overlay analyses to calculate:
        a. Total area (km^2) of each land cover class impacted by cities or sections with agricultural or exurban densities of homes. Cities and sections with exurban densities are buffered by one mile (2.59 km).
        b. Relative abundance (%) of each land cover class impacted by cities, or agricultural or exurban densities of homes, compared with the total area of each class.
        c. Spatial pattern of unimpacted land cover. 'Erase' cities and sections with agricultural or exurban densities of rural homes from the land cover map. Cities and sections with exurban densities are buffered by one mile (2.59 km). Calculate from this new land cover map:
            i. Number of patches and average patch size (m^2).
            ii. Mean distance to nearest neighbor (m).
                1. Trajectories of change in residential land use by land cover class. calculate change in cover type for each pixel over time.
                2. Summarize net gains and losses of percent cover change for each land cover class (see Figure 3 as an example).

Table 2-1. Contact information for acquiring rural homes data from county tax assessors.

State	Department	State Contact	County	Address	Contact Name and Telephone	Data Format
Montana	Montana Department of Revenue, Tax Policy and Research www.state.mt.us/revenue/rev.htm	Dallas Reese, Tax Policy Analyst PO Box 8505 Helena, MT 59604-5805 (406) 444-2668	Bighorn	121 W. Third St. Hardin, MT 50034	(406) 665-9710	Electronic spreadsheet
			Carbon	17 West 11th St. Red Lodge, MT 59068	(406) 446-1223	
			Gallatin	2273 Boot Hill Ct. Suite 100 Bozeman, MT 59715	(406) 582-3400	
			Madison	PO Box 307 Virginia City, MT 59755	(406) 843-5335	
			Park	414 E. Callendar St. Livingston, MT 59047	(406) 222-4113	
			Stillwater	400 Third Ave. North Columbus, MT 59019	(406) 322-8015	
			Sweet Grass	200 W. Third St. Big Timber, MT 59011	(406) 932-5149	
Wyoming	Wyoming Department of Revenue, Ad Valorem Tax Division http://revenue.state.wy.us	Jim Felton, Local Assessed Supervisor Herschler Building 2nd Floor West 122 W. 25th St. Cheyenne, WY 82002-0110 (307) 777-7961	Bighorn			Electronic spreadsheet
			Fremont			
			Hot Springs			
			Lincoln			
			Park			
			Sublette			
			Teton			

Table 2-1 continued. Contact information for acquiring rural homes data from county tax assessors.

State	Department	State Contact	County	Address	Contact Name and Telephone	Data Format
Idaho	County Tax Assessor		Bear Lake	PO Box 190 Paris, ID 83261	Lynn Lewis; (208) 945-2155	Paper; data compiled by user at tax office
			Bonneville	605 N. Capital Ave. Idaho Falls, ID 83402	Geri Keele; (208) 529-1320	Paper or electronic copies distributed to user
			Caribou	PO Box 775 Soda Springs, ID 83276	Carol; (208) 547-4749	Paper; data compiled by user at tax office
			Clark	PO Box 7 Dubois, ID 83423	Betty Kirkpatrick; (208) 374-5404	Paper or electronic copies distributed to user
			Franklin	51 W. Oneida Preston, ID 83263	Rich Umbel; (208) 852-1091	Paper or electronic copies distributed to user
			Fremont	151 W. 1st N. #2 St. Anthony, ID 83445	Ivel Burrell; (208) 624-7984	Paper or electronic copies distributed to user
			Madison	PO Box 389 Rexburg, ID 83440	Craig Rindlesbacher; (208) 359-3020 ext.317	Paper or electronic copies distributed to user
			Teton	PO Box 756 Driggs, ID 83422	Danny Thomas; (208) 354-3507	Paper; data compiled by user at tax office

SOP 3. Monitoring and Analyses of Change in Roads

1. Go to USCB website www.census.gov . Navigate to the 'Geography' page and find the most recent decennial TIGER/Line files (e.g. 1990, 2000, 2010).
2. Download a compressed (.zip) file for counties within Montana, Wyoming, and Idaho that fall within the GRYN (Table 3-1). Create a separate folder for each zipped file, because there are 16 files for each county which are necessary to make the GIS coverage. Unzipped files have the extension .RTxx. Also download the Adobe Acrobat file that explains the TIGER data (e.g. ***tiger2k.pdf*** in 2000).
3. Use ArcToolbox (conversion tools) to import the TIGER files into a GIS polygon coverage, resulting in one coverage per county. ArcToolbox allows you to specify the projection and coordinate system while importing (UTM zone 12, datum NAD83). A point coverage is also created for each county, but these can be deleted.
4. Open all of the county coverages in a GIS (e.g. ArcView), convert them to shapefiles, and merge them into one file for the state.
5. CFCC (Census Feature Class Code) is the field in the attribute table that identifies line type. Those starting with 'A' are roads. Refer to the TIGER PDF file (e.g. pages 3-27 to 3-30 of ***tiger2k.pdf***) for descriptions of road types.
6. In the query builder, select all line types starting with 'A' except A65, A71, and A72 (these are not roads). Delete all other records.
7. Delete all fields except 'CFCC', 'STATEl' (rename 'STATE'), and 'COUNTYl' (rename 'COUNTY'). Recalculate length as a new field.
8. Reclassify to five classes according to the 'road class' in Table 3-2.
    a. Create a new field called CFCC_1.
    b. For each of the five classes, select appropriate CFCC values and then calculate the new value in CFCC_1. For example, for class A1, select CFCC values A11-18 and A63, then calculate CFCC_1 values as 'A1'. Do this separately for each class.
9. We recommend completing a new map of roads every 10 years using updated TIGER files.
10. Calculate the total length (km) of roads within each class of roads (Table 3-2).
11. Every 10 years, evaluate percent change in this metric since previous monitoring periods, i.e. [(current value – value at last time period)/value at last time period].

Table 3-1. Counties that fall within the boundaries of the GRYN land use study area.

State	State FIPS number	County	County FIPS number
Montana	30	Bighorn	3
		Carbon	9
		Gallatin	31
		Madison	57
		Park	67
		Stillwater	95
		Sweet Grass	97
Wyoming	56	Bighorn	3
		Fremont	13
		Hot Springs	17
		Lincoln	23
		Park	29
		Sublette	35
		Teton	39
Idaho	16	Bear Lake	7
		Bonneville	19
		Caribou	29
		Clark	33
		Franklin	41
		Fremont	43
		Madison	65
		Teton	81

Table 3-2. Hierarchical classification scheme for roads. Monitoring road classes represent aggregated USCB TIGER/Line road classes.

Road Class	Class Code	TIGER Class Code (CFCC)
Primary Road: Interstate	A1	A11-18, A63
Primary Road: US Highway	A2	A21-28
Secondary Road: State/County Highway	A3	A31-38
Local Road: Paved and Unpaved	A4	A41-48, A60-62, A64, A70, A73-74
4WD/Logging Road	A5	A51-53

SOP 4. Monitoring and Analyses of Change in Agriculture

1. Go to the USDA NASS Census of Agriculture webpage http://www.nass.usda.gov/census . Navigate to 'Quick Stats' to conduct a query of the most recent census data (e.g. 'Query for 2002 Census Data').
2. Get data on Level I Agriculture (Table 4-1) using Census of Agriculture:
    a. Navigate to Census of Agriculture, state-county page.
    b. Select data type = 'state-county'.
    c. Select the table representing farms, land in farms, value of land and buildings, and land use for the most recent census (e.g. called Table 8 for the 2002 census).
    d. Select multiple data items at once for the current year, including:
        i. Farms and land in farms - Land in Farms (acres)
        ii. Farms and land in farms – Approx. land area - Proportion in farms (%)
        iii. Land in farms, according to use - Total cropland (acres)
        iv. Land in farms, according to use - Pastureland – All types (acres)
    e. Select Montana, then the GRYN counties for Montana (see Table 3-1).
    f. Get the data in GIS format, which is a database (.dbf) that can eventually be linked to a county basemap shapefile in a GIS.
    g. This database consists of one record per agricultural class per county. Open the database in Microsoft Excel and modify this database so that each of the four agricultural classes is a new field (copy data from the original data field into these new fields), and there is only one record per county. Delete the unecessary fields (keep the state/county information).
    h. Copy all cells into a new database (otherwise it won't save correctly) and save as a .dbf.
3. Get data on Level III and IV cropland classes (Table 4-1) using 'County Data':
    a. Query selected counties within a state for 'crops', and choose Montana.
    b. Highlight all crops (commodities) then click the 'irrigated' and 'non-irrigated' boxes.
    c. Select the current year (e.g. 2002 to 2002).
    d. Select the GRYN counties for Montana (see Table 3-1).
    e. Choose the .csv file format, which is a database that can eventually be linked to a county basemap shapefile in a GIS.
    f. This database consists of one record per commodity per county. Open the database in ArcView and modify so that there is one record per county and four new fields to represent the four cropland classes (irrigated and non-irrigated hay and 'other crops').
        i. For commodities with an 'All' category, delete records for other commodities that represent subcategories (e.g. Keep 'Wheat – All', but delete 'Wheat – Winter' and 'Wheat – Other', etc.).
        ii. There are two fields that represent acreage for that crop, including 'planted' and 'harvested'. Acres planted is the value to keep. However, some records do not have a value for this field (e.g. hay), and in those cases, 'harvested' is the value to keep. Therefore, consolidate these two fields into a new one called 'acres', with values in 'planted' supersceding

‘harvested’ when they exist. The new ‘acres’ field should then have a value > 0 populating every cell.

   iii. Delete all fields except state, county, state and county fips, commodity, practice, commcode, praccode, year, acres.
   iv. Using ‘summarize field’, summarize the four commodities (irrigated hay, dry (non-irrigated) hay, irrigated other crops (sum of all commodities besides hay), dry other crops (sum of all commodities besides hay)) by ‘acres’ per county (i.e. field summary variable is ‘county’, sum ‘acres’ to summarize). This creates a .dbf file for each of the four commodities, with one record per county and a field representing acreage for that commodity. Also create a geographic header summary, including the ‘first’ value for the state and county information.
   v. Rename the field titles for each commodity, including the year in the title (e.g. irrhay_05, dryhay_05, irrothcr_05, dryothcr_05).
   vi. Cut and paste the fields from the .dbf files into the geographic header .dbf. This creates one .dbf that includes state, county, statefips, countyfips, year, irrhay_xx, dryhay_xx, irrothcr_xx, dryothcr_xx. Copy all cells into a new .dbf (otherwise it won’t save correctly).

4. Open both of these .dbf files in Microsoft Excel. Verify that the counties are in the same order in each file, then copy all fields from one .dbf into the other.
5. Delete duplicate fields. Copy all cells into a new .dbf (otherwise it won’t save correctly).
6. Repeat this process for Wyoming and Idaho. Merge the three databases into one .dbf file for the entire study area.
7. For the initial monitoring period:
   a. Add this .dbf and the county basemap shapefile (***countiesgryn.shp***) to a GIS.
   b. Join the attribute table of the shapefile with the .dbf table by the unique field representing the concatenated state and county FIPS number. In 2002, this field existed in both the attribute table (‘fips’) and the .dbf (‘stcofips’); in the future, if it does not exist, create this field by concatenating the state and county FIPS numbers.
   c. Save this join as a new shapefile (e.g. agriculture.shp).
8. For subsequent monitoring periods:
   a. Add this .dbf from the current monitoring period and the shapefile from the previous monitoring period (e.g. agriculture.shp) into a GIS.
   b. Join the attribute table of the shapefile with the .dbf by the unique fiels representing the concatenated state and county FIPS number. If this field does not exist in the new .dbf, create it by concatenating the state and county FIPS numbers.
   c. Save this join as a shapefile with this appended attribute table so that it includes the new fields from the current monitoring period and the fields from previous monitoring. This new shapefile should then replace the one from the previous monitoring period.
9. We recommend creating a new map of agriculture every 5 years using updated Census of Agriculture data.
10. Calculate metrics for each class of agriculture (Table 4-1), including total area (acres) and relative abundance compared with total land area (%).

11. Every 5 years, evaluate percent change for each of these metrics since previous monitoring periods, i.e. [(current value – value at last time period)/value at last time period].

Table 4-1. Monitoring classes derived from Census of Agriculture data.

Level I	Level II	Level III	Level IV
Agriculture			
	Irrigated agriculture		
		Cropland	
			Hay
			Other crop
		Pasture	
	Non-irrigated agriculture		
		Cropland	
			Hay
			Other crop
		Pasture	

Table 1. Previous land cover and use classification efforts using remotely-sensed data in the GRYN study area.

Sensor	Platform	Source	Citation	Spatial Extent	Time	Resolution
Hyperspectral AVIRIS	Aircraft	NASA	Kokaly et al. 2003	Portion of YNP	1996	15m
Hyperspectral Probe-1	Aircraft	Commercial	Aspinall 2002	Confluence of Lamar River, Soda Butte Creek, Cache Creek in YNP	1999	5m
Multispectral Landsat ETM+	Satellite	USGS	Lawrence et al. 2004	GYE	1999-2000	30m
Multispectral IKONOS	Satellite	Commercial		California	2001	4m
Hyperspectral Probe-1	Aircraft	Commercial		Virginia City, MT	1999	5m
Landsat TM	Satellite	USGS	Aspinall and Pearson 2000	Upper Yellowstone River catchment	1985, 1999	30m
Landsat TM	Satellite	USGS	Jakubauskas and Price 1997	Central Plateau region of YNP	1991	30m
Landsat MMS and TM	Satellite	USGS	Parmenter et al. 2003	GYE	1975, 1985, 1995	80m
Landsat TM	Satellite	USGS	Burrough et al. 2001	Western GYE	1991	30m
Landsat TM	Satellite	USGS	Jakubauskas 1996	Central Plateau region of YNP	1991	30m
Landsat TM	Satellite	USGS	Hansen et al. 1999	Western portion of GYE	1991	30m
Landsat TM 4	Satellite	USGS	Turner et al. 1994	Subalpine plateau of YNP	1989	30m
Landsat TM	Satellite	USGS	Price and Jakubauskas 1998	Central Plateau region of YNP	1991	30m
Landsat TM	Satellite	USGS	Debinski et al. 1999	Northwest corner of GYE	1991	1 ha
Landsat TM and ETM	Satellite	USGS	Powell (2004)	Most of GYE		30m
Landsat TM and ETM	Satellite	USGS	Baker 2004	Gallatin Valley, MT	1988, 2001	30m
Landsat 5 MMS	Satellite	USGS	Merrill et al. 1993	Northeast portion of YNP	1972, 1986	70m
Landsat TM	Satellite	USGS	GAP analysis	States	1991	30m
Landsat TM	Satellite	USGS	Vogelmann et al. 2001	National	1992	30m
MODIS	Satellite	NASA	Wessels et al. 2004	GYE	2001	250m

Table 2. Summary of remotely sensed and ancillary data sources for monitoring land use change in the GRYN.

Objective	Data Source	Time Scale of Data	Time Scale of Monitoring	Extent	Spatial Resolution	Format of Data	Price	Transformations to Data	Software
Land Cover	Landsat (USGS EROS Data Center)	~16 days	5 years	Global; GRYN=13 scenes	30m	Precision and terrain corrected satellite imagery	~$625 per scene	Classify raw images into land cover map	Image processing software, such as ERDAS Imagine (Leica Geosystems 2003); GIS software, such as ESRI ArcView (1999) or ArcGIS (2002); Statistical software, such as R (R Development Core Team 2003) or SAS (SAS Institute 2001)
	Aerial Photos	Variable		Local and regional		Hard copy or digital photos	Variable	None	
	DEM (USGS)	10 years		National		GIS grid	Free	Change projection	
Land Use: Ancillary Rural Homes	County Tax Assessors	1-2 years	5 years	Distributed by county	Square mile	Paper records or electronic spreadsheet; parcel basemap as GIS layer	Free	Paper records input to digital format; Digital data linked to GIS through parcel id	Data processing software, such as Microsoft Excel or Access (Microsoft Corporation 2002); GIS software
Land Use: Ancillary Incorporated Cities	US Census Bureau	10 years	10 years	Distributed by county	USCB Block	Shapefile or coverage of incorporated areas (i.e. 'census places')	Free	Change projection, mosaic counties	GIS software
Land Use: Ancillary Agriculture	USDA National Ag. Statistics Services	5 years	5 years	Distributed by State	County	Report and spreadsheet	Free	Link agriculture data to county basemap	Data processing software; GIS software
Land Use: Ancillary Roads	TIGER/ Line files (USCB)	10 years	10 years	Distributed by county	Road	TIGER / Line file	Free	Import TIGER files as lines into GIS	GIS software

Table 3. Classification scheme for monitoring land use which integrates remotely-sensed and ancillary data sources.

Level I	Level II	Level III	Level IV	Potential Remote Sensing Data Sources*				Chosen Data Source (Resolution)
				MODIS	Landsat	Hyperspectral	LiDAR	
Natural vegetated				x	**X**	x		
	Herbaceous / Shrubland			x	**X**	x		Remote Sensing (30 meter)
	Deciduous forest				**X**	x		Remote Sensing (30 meter)
			Aspen		**X**	x		Remote Sensing (30 meter)
			Willow		**X**	x		Remote Sensing (30 meter)
			Cottonwood		**X**	x		Remote Sensing (30 meter)
	% Conifer forest			x	**X**	x		Remote Sensing (30 meter)
		Seedling/ Sapling			**X**	x	x	Remote Sensing (30 meter)
		Pole-aged			**X**	x	x	Remote Sensing (30 meter)
		Mature			**X**	x	x	Remote Sensing (30 meter)
			Whitebark pine		**X**	x		Remote Sensing (30 meter)
			Douglas-fir		**X**	x		Remote Sensing (30 meter)
			Mixed conifer species		**X**	x		Remote Sensing (30 meter)
		Mixed seral			**X**	x	x	Remote Sensing (30 meter)
Natural non-vegetated				x	**X**	x		
	Water				**X**	x		Powell (30 meter)
	Other				**X**	x		Powell (30 meter)
Agriculture								USDA Census of Ag (county)
	Irrigated agriculture			x	**X**	x		Powell (30 meter)
		Cropland						USDA Census of Ag (county)
			Hay					USDA Census of Ag (county)
			Other crop					USDA Census of Ag (county)
		Pasture						USDA Census of Ag (county)
	Non-irrigated agriculture							USDA Census of Ag (county)
		Cropland						USDA Census of Ag (county)
			Hay					USDA Census of Ag (county)
			Other crop					USDA Census of Ag (county)
		Pasture						USDA Census of Ag (county)
Non-natural non-vegtated								
	Urban/Built-up				**X**	x		Remote Sensing (30 meter)
		Rural homes						County tax offices (mi^2)
			Agricultural density					County tax offices (mi^2)
			Exurban density					County tax offices (mi^2)
		Incorporated cities						USCB (Block)
		Roads						USCB (Block)
			Interstate					USCB (Block)
			US highway					USCB (Block)
			State / County highway					USCB (Block)
			Local (paved / unpaved)					USCB (Block)
			Four-wheel drive					USCB (Block)

*Bold X's indicate the chosen data source for this monitoring effort.

Table 4. Metrics to calculate for each land cover and use class during each monitoring time period.

Level I	Level II	Level III	Level IV	Total Area	Relative Abundance	# of Patches	Patch Size	Distance to Neighbor	Other
Natural vegetated									
	Herbaceous / Shrubland			x	x	x	x	x	
	Deciduous forest			x	x	x	x	x	
			Aspen	x	x	x	x	x	
			Willow	x	x	x	x	x	
			Cottonwood	x	x	x	x	x	
	% Conifer forest			x	x	x	x	x	
		Seedling/ Sapling		x	x	x	x	x	
		Pole-aged		x	x	x	x	x	
		Mature		x	x	x	x	x	
			Whitebark pine	x	x	x	x	x	
			Douglas-fir	x	x	x	x	x	
			Mixed conifer species	x	x	x	x	x	
		Mixed seral		x	x	x	x	x	
Natural non-vegetated									
	Water			x	x	x	x	x	
	Other			x	x	x	x	x	
Agriculture				x					
	Irrigated agriculture			x	x	x	x	x	
		Cropland		x	x				
			Hay	x	x				
			Other crop	x	x				
		Pasture		x	x				
	Non-irrigated agriculture			x	x				
		Cropland		x	x				
			Hay	x	x				
			Other crop	x	x				
		Pasture		x	x				
Non-natural non-vegetated									
	Urban / Built-up			x	x				
		Rural homes							Total # of homes
			Agricultural density	x	x				
			Exurban density	x	x				
		Incorporated cities		x	x				
		Roads							Total length
			Interstate						Total length
			US highway						Total length
			State / County highway						Total length
			Local (paved / unpaved)						Total length
			Four-wheel drive						Total length

Table 5. Example of table format for reporting results of land cover and use monitoring data and analyses.

Class	Total Area			Relative Abundance			# of Patches			Mean Patch Size			Mean Distance to Neighbor		
	2015	2010	% Change	2015	2010	% Change	2015	2010	% Change	2015	2010	% Change	2015	2010	% Change
Herbaceous/Shrubland	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Deciduous forest	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Aspen	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Willow	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Cottonwood	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
% Conifer forest	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Seedling/Sapling	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Pole-aged	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Mature	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Whitebark pine	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Douglas-fir	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Mixed conifer	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Mixed seral	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Water	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Other natural non-vegetated	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Irrigated agriculture	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Urban/Built-up	#	#	#	#	#	#	--	--	--	--	--	--	--	--	--

Table 6. Example of table format for reporting results of residential land use monitoring data and analyses.

Class	Total Area			Relative Abundance			# of Homes		
	2015	2010	% Change	2015	2010	% Change	2015	2010	% Change
Rural homes	--	--	--	--	--	--	#	#	#
Agricultural densities	#	#	#	#	#	#	--	--	--
Exurban densities	#	#	#	#	#	#	--	--	--
Incorporated cities	#	#	#	#	#	#	--	--	--

Table 7. Example of table format for reporting results of roads monitoring data and analyses.

Class	Total Length		
	2015	2010	% Change
Roads	#	#	#
Interstate	#	#	#
US highway	#	#	#
State/County highway	#	#	#
Local road	#	#	#
Four-wheel drive road	#	#	#

Table 8. Example of table format for reporting results of agriculture monitoring data and analyses.

Class	Total Area			Relative Abundance		
	2015	2010	% Change	2015	2010	% Change
Agriculture	#	#	#	#	#	#
Irrigated	#	#	#	#	#	#
Cropland	#	#	#	#	#	#
Hay	#	#	#	#	#	#
Other	#	#	#	#	#	#
Pasture	#	#	#	#	#	#
Non-irrigated	#	#	#	#	#	#
Cropland	#	#	#	#	#	#
Hay	#	#	#	#	#	#
Other	#	#	#	#	#	#
Pasture	#	#	#	#	#	#

Figure 1. Study area for monitoring land use change around parks of the GRYN.

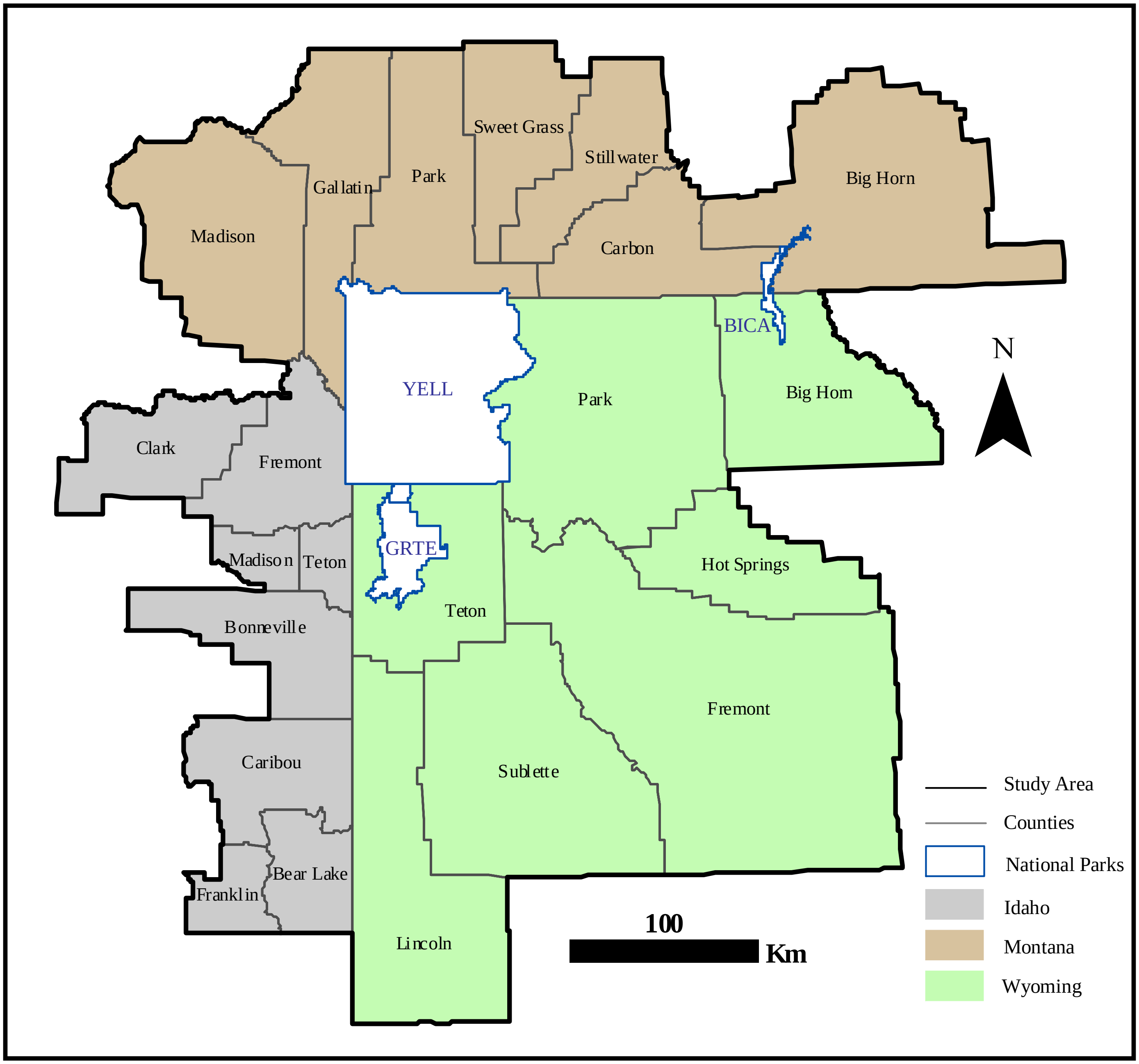

Figure 2. Locations of Landsat scenes and aerial photo transects used for creating land cover maps.

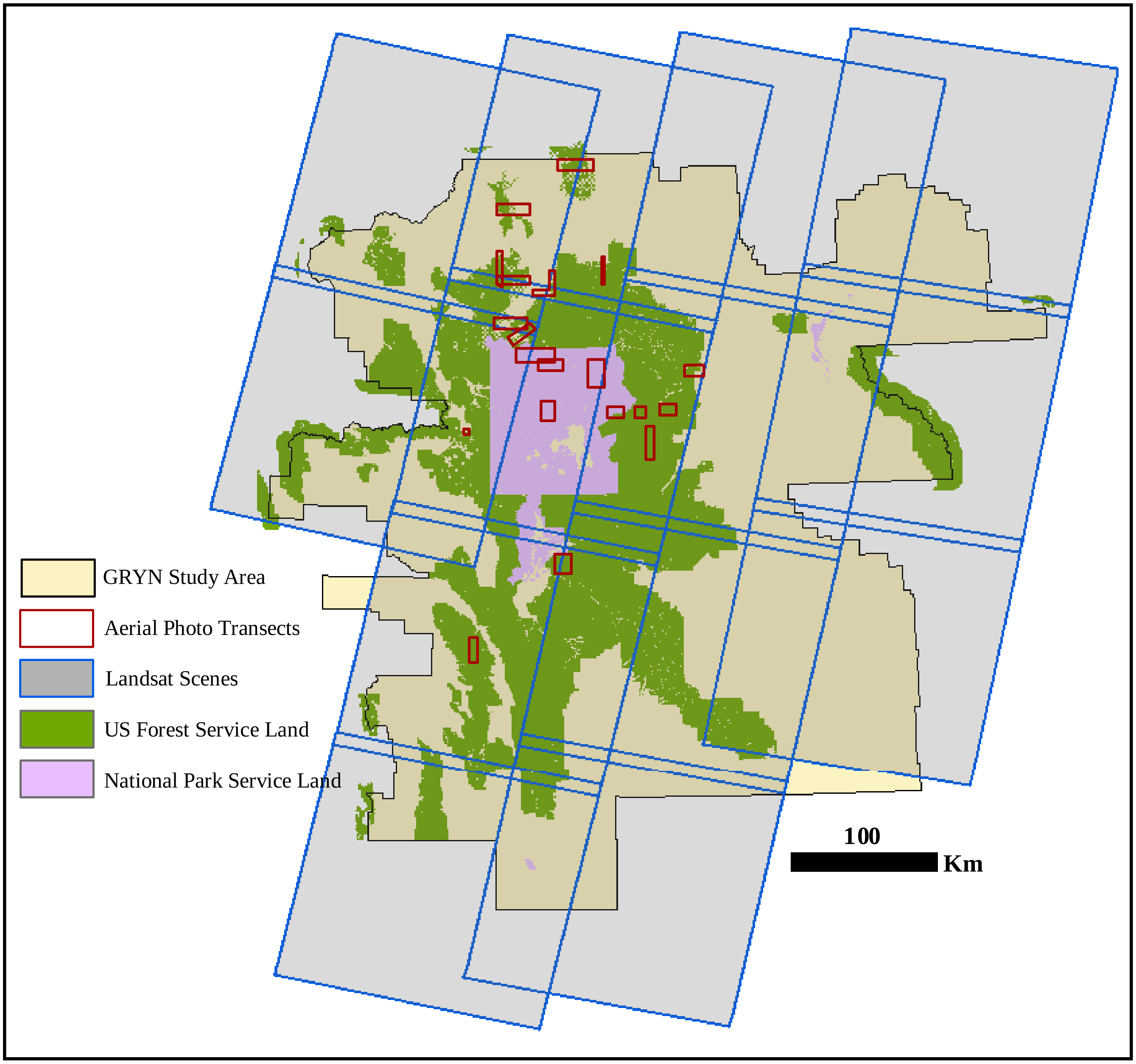

Figure 3. Diagram showing analyses of trajectories by Parmenter et al. (2003). Arrows indicate pathways of net gains and losses of percent cover change in the Greater Yellowstone Ecosystem from 1975-1995. MXWD = Mixed woody deciduous/herbaceous, MXCON = Mixed conifer/herbaceous. Cover types represented here differ slightly from those used in the GRYN land use classification scheme (Table 3).

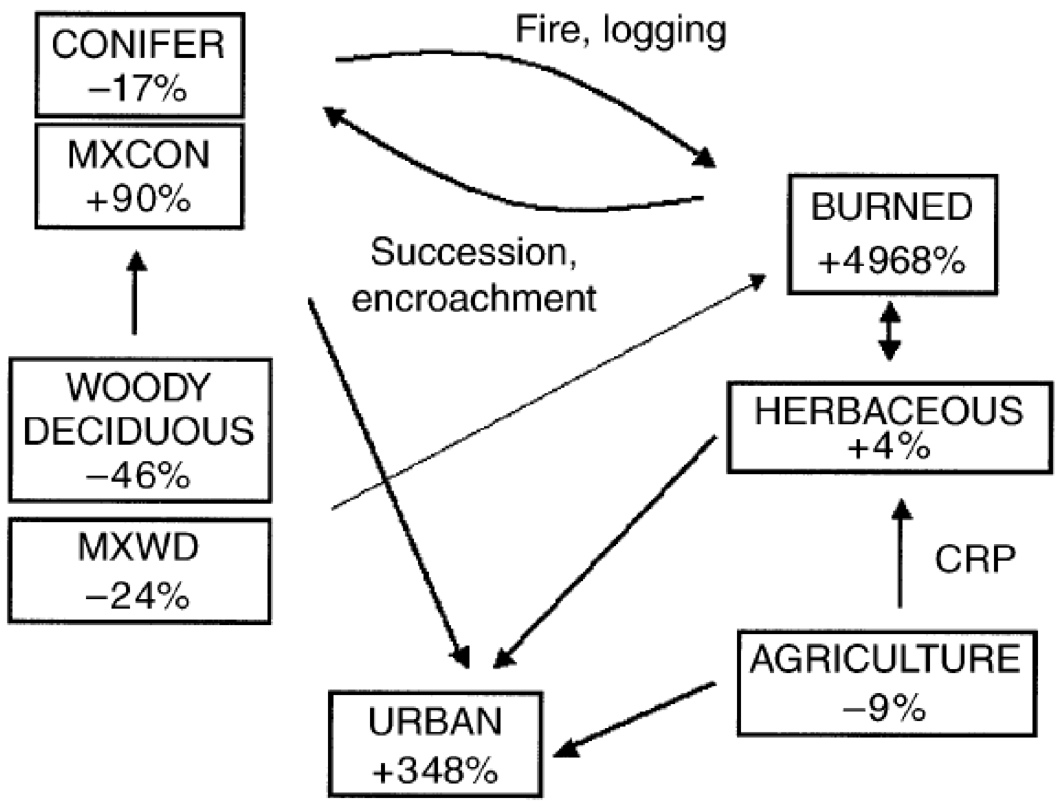

Figure 4. Observed numbers of rural homes and forecasts of future rural homes by Gude et al. (in prep) in the GYE. Three possible alternative future growth scenarios, based on historical patterns of growth, are shown for 2010 and 2020. Areas where growth in housing was greater than one standard deviation above the mean are shown as core growth areas.

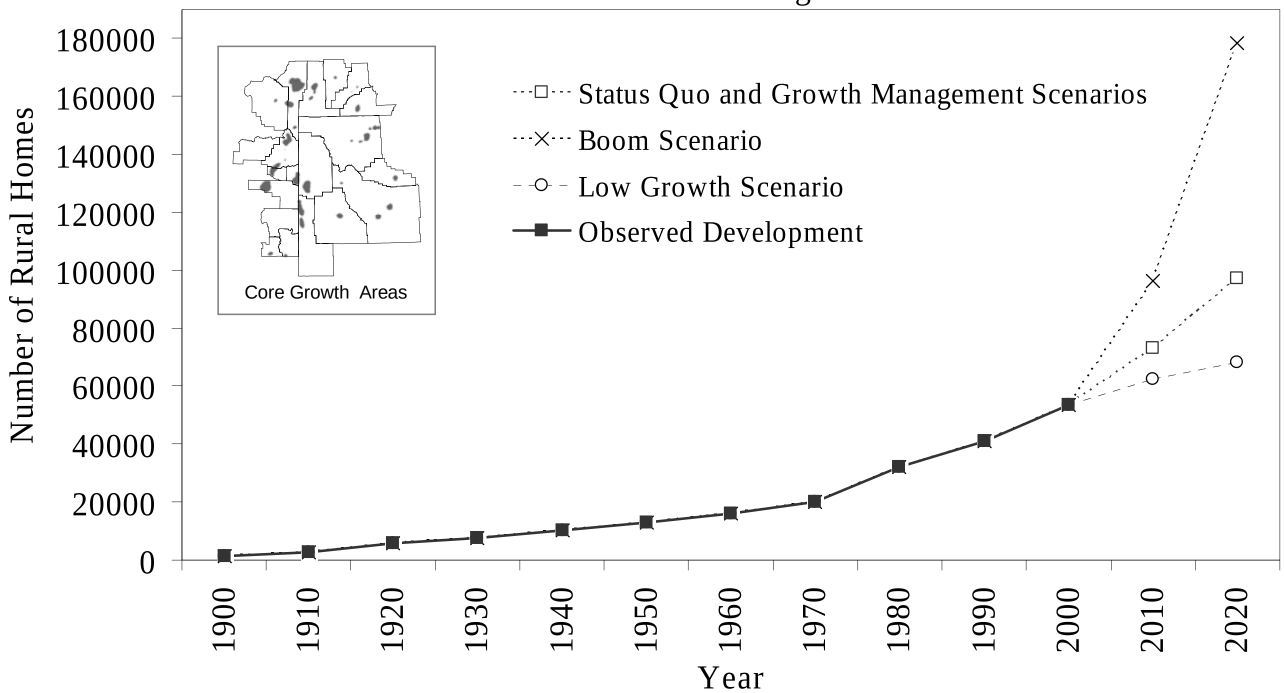

Figure 5. Projected ecological impacts of future rural home development in the GYE in 2020 based on the Status Quo scenario of growth, which assumes historical rates of growth will continue in the future (Gude et al. in prep). Red and yellow areas depict habitat that is of high value to sensitive resources within the GYE, including riparian areas, bird hotspots, potential corridors, and irreplaceable areas. Red areas depict habitat that is impacted by exurban and agricultural densities of rural homes, and yellow depicts habitat that is not impacted by rural homes. Areas that are not red or yellow are not habitat.

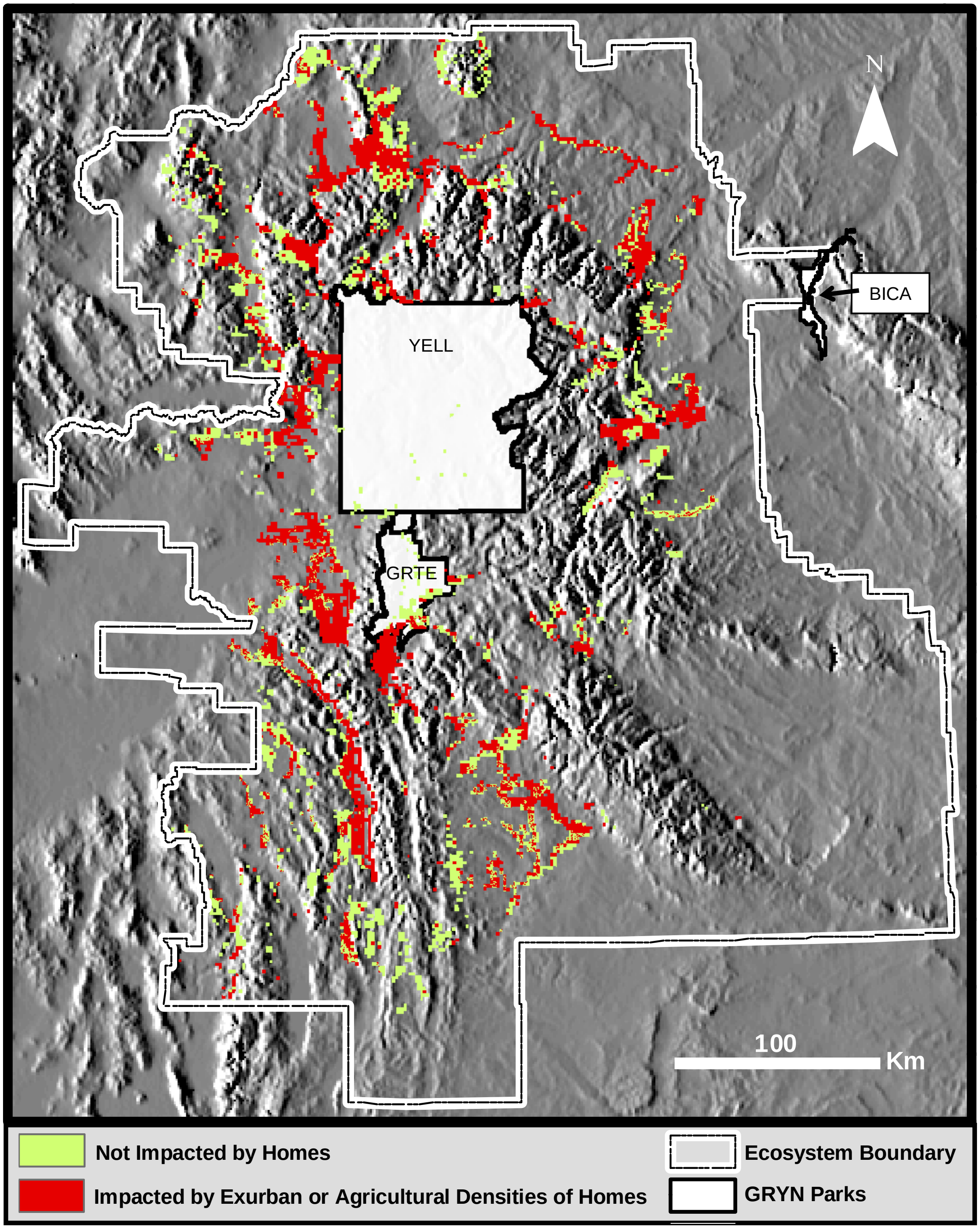

Figure 6. Example of a land cover map of the GYE created by Parmenter et al. (2003). Cover types differ slightly from those in the GRYN classification scheme.

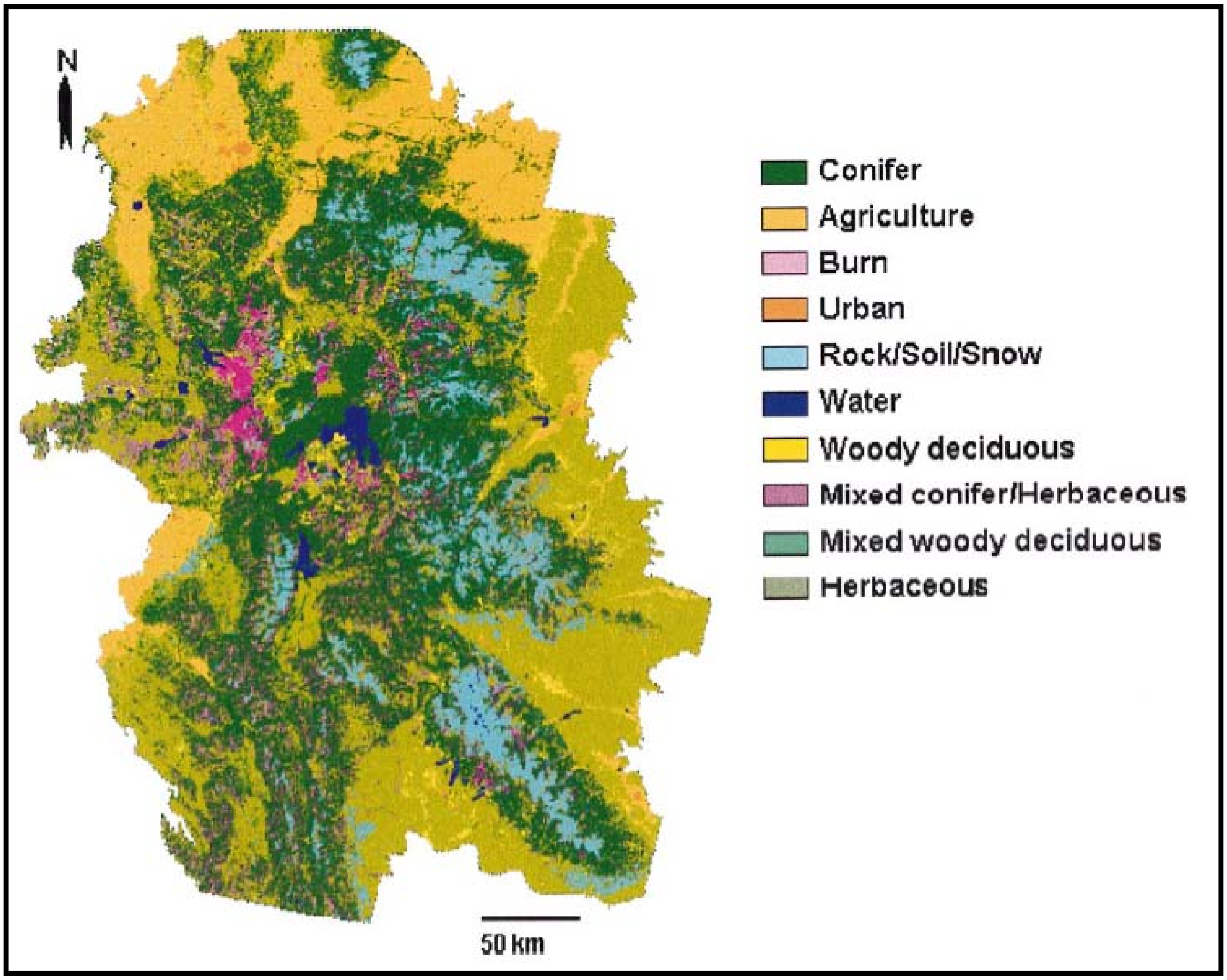

Figure 7. Example of a map representing residential land uses within the GYE from data compiled by Hernandez (2004).